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Street, Suite 433, MSC 1119, Charleston, SC 29403 (US).
SCHEIN, Douglas; 2420 N. Seminary #1, Chicago, IL
60614 (US).

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(74) Agents: **OLIFF, James, A.** et al.; Oliff & Berridge, PLC,
P.O. Box 19928, Alexandria, VA 22320 (US).

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(71) Applicant: **ORGAN RECOVERY SYSTEMS INC.**
[US/US]; 2570 E. Devon Avenue, Des Plaines, IL 60018
(US).

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(72) Inventors: **OWEN, Donald, R.**; Biosyn, Inc., 5700
Citrus Boulevard, Suite B, Harahan, LA 70123 (US).
KRAVITZ, David, C.; Life Science Holdings, Inc., 2570
E. Devon Avenue, Des Plaines, IL 60018 (US). **BRASSIL,**
John; 1137 Jeffrey Court West, Northbrook, IL 60062
(US). **BROCKBANK, Kelvin, G., M.**; 81 Rutledge
Avenue, Charleston, SC 29401 (US). **BURROUGHS,**
Andrew; 7404 7th Avenue, Kenosha, WI 53143 (US).
ISAACS, Dickon; 1426 N. Greenvue #2, Chicago, IL
60622 (US). **STEIBEL, Dennis, J.**; 1295 Thorndale Lane,
Lake Zurich, IL 60047 (US). **FRASER, Richard**; 2083
Westridge Boulevard, Bortlett, IL 60103 (US). **HARRIS,**
Stanley; Organ Recovery Systems, Inc., 701 E. Bay

(54) Title: **APPARATUS AND METHOD FOR MAINTAINING AND/OR RESTORING VIABILITY OF ORGANS**

(57) Abstract: An organ perfusion apparatus and method monitor, sustain and/or restore viability of organs and preserve organs for storage and/or transport. Other apparatus include an organ transporter, an organ cassette and an organ diagnostic device. The method includes perfusing the organ at hypothermic and/or normothermic temperatures, preferably after hypothermic organ flushing for organ transport and/or storage. The method can be practiced with prior or subsequent static or perfusion hypothermic exposure of the organ. Organ viability is restored by restoring high energy nucleotide (e.g., ATP) levels by perfusing the organ with a medical fluid, such as an oxygenated cross-linked hemoglobin-based bicarbonate medical fluid, at normothermic temperatures. In perfusion, organ perfusion pressure is preferably controlled in response to a sensor disposed in an end of tubing placed in the organ, by a pneumatically pressurized medical fluid reservoir, providing perfusion pressure fine tuning, overpressurization preventing and emergency flow cut-off. In the hypothermic mode, the organ is perfused with a medical fluid, preferably a simple crystalloid solution containing antioxidants, intermittently or in slow continuous flow. The medical fluid may be fed into the organ from an intermediary tank having a low pressure head to avoid organ overpressurization. Preventing overpressurization prevents or reduces damage to vascular endothelial lining and to organ tissue in general. Viability of the organ may be automatically monitored, preferably by monitoring characteristics of the medical fluid perfusate. The perfusion process can be automatically controlled using a control program.

APPARATUS AND METHOD FOR MAINTAINING AND/OR RESTORING VIABILITY OF ORGANS

BACKGROUND OF THE INVENTION

5 This application is a continuation-in-part of U.S. Patent Application No. 09/537,180, filed March 29, 2000, which is a continuation-in-part of U.S. Patent Application No. 09/162,128, filed September 29, 1998, the entire contents of which are hereby incorporated by reference.

1. Field of Invention

10 The invention relates to an apparatus and method for perfusing one or more organs to monitor, sustain and/or restore the viability of the organ(s) and/or for transporting and/or storing the organ(s).

2. Description of Related Art

15 Preservation of organs by machine perfusion has been accomplished at hypothermic temperatures with or without computer control with crystalloid perfusates and without oxygenation. See, for example, U.S. Patents Nos. 5,149,321, 5,395,314, 5,584,804, 5,709,654 and 5,752,929 and U.S. Patent Application No. 08/484,601 to Klatz et al., which are hereby incorporated by reference. Hypothermic temperatures provide a decrease in organ metabolism, lower the energy
20 requirements, delay the depletion of high energy phosphate reserves and accumulation of lactic acid and retard the morphological and functional deterioration associated with disruption of blood supply. Oxygen can not be utilized efficiently by mitochondria below approximately 20°C to produce energy, and the reduction in catalase/superoxide dismutase production and ascorbyl and glutathione regeneration at
25 low temperatures allows high free radical formation. The removal of oxygen from perfusates during low temperature machine perfusion has even proven helpful in improving organ transplant results by some investigators.

Reduction in potential oxygen damage is also accomplished via the addition of
antioxidants to the perfusate. In particular, this has proven useful in reducing organ
30 damage after long warm ischemia times. Numerous other perfusate additives have also been reported to improve the outcome of machine perfusion.

Ideally organs would be procured in a manner that limits their warm ischemia time to essentially zero. Unfortunately, in reality, many organs, especially from non-beating heart donors, are procured after extended warm ischemia time periods (i.e., 45 minutes or more). The machine perfusion of these organs at low temperature has demonstrated significant improvement (Transpl Int 1996 Daemen). Further, prior art teaches that the low temperature machine perfusion of organs is preferred at low pressures (Transpl. Int 1996 Yland) with roller or diaphragm pumps delivering the perfusate at a controlled pressure. Numerous control circuits and pumping configurations have been utilized to achieve this objective and to machine perfuse organs in general. See, for example, U.S. Patents Nos. 5,338,662 and 5,494,822 to Sadri; U.S. Patent No. 4,745,759 to Bauer et al.; U.S. Patents Nos. 5,217,860 and 5,472,876 to Fahy et al.; U.S. Patent No. 5,051,352 to Martindale et al.; U.S. Patent No. 3,995,444 to Clark et al.; U.S. Patent No. 4,629,686 to Gruenberg; U.S. Patents Nos. 3,738, 914 and 3,892,628 to Thorne et al.; U.S. Patents Nos. 5,285,657 and 5,476,763 to Bacchi et al.; U.S. Patent No. 5,157,930 to McGhee et al.; and U.S. Patent No. 5,141,847 to Sugimachi et al. However, in some situations the use of such pumps for machine perfusion of organs may increase the risk of overpressurization of the organ should the organ perfusion apparatus malfunction. High pressure perfusion (e.g., above about 60 mm Hg) can wash off the vascular endothelial lining of the organ and in general damages organ tissue, in particular at hypothermic temperatures where the organ does not have the neurological or endocrinal connections to protect itself by dilating its vasculature under high pressure.

Furthermore, the techniques used for assessment of the viability of these machine perfused organs have been a critical factor in limiting the organs from greater use. While increased organ resistance (i.e., pressure/flow) measurements during machine perfusion are a useful indicator, they demonstrate only the worst case situations.

During low temperature machine perfusion of organs that have been damaged by warm ischemia time or by the machine perfusion itself, the organs will elute intracellular and endothelial as well as membrane constituents. Over the years the appearance of various ubiquitous intracellular enzymes, such as lactic dehydrogenase (LDH) and alkaline phosphatase, in the perfusate has been used as a biomarker of organ damage. Recently, the determination of the presence of alpha glutathione-S-

transferase (a-GST) and Pi glutathione-S-transferase (p-GST) in low temperature machine perfusion perfusates has proven a satisfactory indicator in predicting the functional outcome of non-beating heart donor kidney grafts before transplantation (Transpl 1997 Daemen).

5 The prior art has also addressed the need to restore or maintain an organ's physiological function after preservation for an extended period of time at hypothermic temperatures. In particular, U.S. Patent No. 5,066,578 to Wikman-Coffelt discloses an organ preservation solution that contains large amounts of pyruvate. Wikman-Coffelt teaches that flooding of the organ with pyruvate bypasses
10 glycolysis, the step in the cell energy cycle that utilizes adenosine triphosphate (ATP) to produce pyruvate, and pyruvate is then available to the mitochondria for oxidative phosphorylation producing ATP. Wikman-Coffelt teaches perfusing or washing an organ at a warm temperature with a first preservation solution containing pyruvate for removal of blood or other debris from the organ's vessels and to vasodilate, increase
15 flow and load the cells with an energy supply in the form of a clean substrate, namely the pyruvate. Wikman-Coffelt teaches that the pyruvate prevents edema, ischemia, calcium overload and acidosis as well as helps preserve the action potential across the cell membrane. The organ is then perfused with a second perfusion solution containing pyruvate and a small percentage of ethanol in order to stop the organ from
20 working, vasodilate the blood vessels allowing for full vascular flow, continue to load the cells with pyruvate and preserve the energy state of the organ. Finally the organ is stored in a large volume of the first solution for 24 hours or longer at temperatures between 4°C and 10°C.

 However, the mitochondria are the source of energy in cells and need
25 significant amounts of oxygen to function. Organs naturally have significant pyruvate levels, and providing an organ with additional pyruvate will not assist in restoring and/or maintaining an organ's full physiological function if the mitochondria are not provided with sufficient oxygen to function. Further, briefly flooding an organ with pyruvate may, in fact, facilitate tearing off of the vascular endothelial lining of the
30 organ.

 U.S. Patent No. 5,599,659 to Brasile et al. also discloses a preservation solution for warm preservation of tissues, explants, organs and endothelial cells. Brasile et al. teaches disadvantages of cold organ storage, and proposes warm

preservation technology as an alternative. Brasile et al. teaches that the solution has an enhanced ability to serve as a medium for the culture of vascular endothelium of tissue, and as a solution for organs for transplantation using a warm preservation technology because it is supplemented with serum albumin as a source of protein and colloid; trace elements to potentiate viability and cellular function; pyruvate and adenosine for oxidative phosphorylation support; transferrin as an attachment factor; insulin and sugars for metabolic support and glutathione to scavenge toxic free radicals as well as a source of impermeant; cyclodextrin as a source of impermeant, scavenger, and potentiator of cell attachment and growth factors; a high Mg^{++} concentration for microvessel metabolism support; mucopolysaccharides, comprising primarily chondroitin sulfates and heparin sulfates, for growth factor potentiation and hemostasis; and ENDO GRO™ as a source of colloid, impermeant and specific vascular growth promoters. Brasile et al. further teaches warm perfusing an organ for up to 12 hours at 30°C, or merely storing the organ at temperatures of 25°C in the preservation solution.

However, flooding an organ with such chemicals is insufficient to arrest or repair ischemic injury where the mitochondria are not provided with sufficient oxygen to function to produce energy. The oxygen needs of an organ at more than 20°C are substantial and cannot be met by a simple crystalloid at reasonable flows. Further, assessment of the viability of an organ is necessary before the use of any type of solution can be determined to have been fruitful.

WO 88/05261 to Owen discloses an organ perfusion system including an organ chamber that is supplied with an emulsion fluid or physiological electrolyte that is transported through a perfusion system. The chamber contains a synthetic sac to hold the organ. Perfusate enters the organ through a catheter inserted into an artery. The perfusate is provided by two independent fluid sources, each of which includes two reservoirs.

30

SUMMARY OF THE INVENTION

The present invention focuses on avoiding damage to an organ during perfusion while monitoring, sustaining and/or restoring the viability of the organ and preserving the organ for storage and/or transport. The invention is directed to an

apparatus and method for perfusing an organ to monitor, sustain and/or restore the viability of the organ and/or for transporting and/or storing the organ. More particularly, the organ perfusion apparatus and method according to the invention monitor, sustain and/or restore organ viability by perfusing the organ at hypothermic temperature (hypothermic perfusion mode) and/or normothermic temperatures (normothermic perfusion mode) preferably after flushing of the organ such as by hypothermic flushing followed by static organ storage and/or organ perfusion at hypothermic temperatures for transport and/or storage of the organ.

The restoring of organ viability may be accomplished by restoring high energy nucleotide (e.g., adenosine triphosphate (ATP)) levels and enzyme levels in the organ, which were reduced by warm ischemia time and/or hypoxia, by perfusing the organ with an oxygenated medical fluid, such as an oxygenated cross-linked hemoglobin-based bicarbonate medical fluid, at normothermic or near-normothermic temperatures. The organ may be flushed with a medical fluid prior to perfusion with the oxygenated medical fluid. Such perfusion can be performed at either normothermic or hypothermic temperatures, preferably at hypothermic temperatures. For hypothermic flush, static storage and hypothermic perfusion, the medical fluid preferably contains little or no oxygen and preferably includes antioxidants, both molecular (e.g., 2-ascorbic acid tocopherol) and enzymatic (e.g., catalase and superoxide dismutase (SOD)). Normothermic and/or hypothermic perfusion, and preferably hypothermic perfusion, can be performed in vivo as well as in vitro. Such perfusion arrests ischemic injury in preparation for transport, storage and/or transplant of the organ.

The normothermic treatment is preferably employed after an organ has been subjected to hypothermic temperatures, statically and/or under perfusion. Such initial hypothermic exposure can occur, for example, during transport and/or storage of an organ after harvesting. The treatment is also suitable for organs that will ultimately be stored and/or transported under hypothermic conditions. In other words, the treatment can be applied to organs prior to cold storage and/or transport.

In the normothermic perfusion mode, gross organ perfusion pressure is preferably provided by a pneumatically pressurized medical fluid reservoir controlled in response to a sensor disposed in an end of tubing placed in the organ, which may be used in combination with a stepping motor/cam valve or pinch valve which provides for perfusion pressure fine tuning, prevents overpressurization and/or provides

emergency flow cut-off. Alternatively, the organ may be perfused directly from a pump, such as a roller pump or a peristaltic pump, with proper pump control and/or sufficiently fail-safe controllers to prevent overpressurization of the organ, especially as a result of a system malfunction. Substantially eliminating overpressurization prevents and/or reduces damage to the vascular endothelial lining and to the organ tissue in general. Viability of the organ may be monitored, preferably automatically, in the normothermic perfusion mode, preferably by monitoring organ resistance (pressure/flow) and/or pH, pO₂, pCO₂, LDH, T/GST, Tprotein, lactate, glucose, base excess and/or ionized calcium levels in the medical fluid that has been perfused through the organ and collected.

An organ viability index may be provided taking into account the various measured factors identified above, such as vascular resistance, pH etc. The index may be organ specific, or may be adaptable to various organs. The index compiles the monitored parameters into a diagnostic summary to be used for making organ therapy decisions and deciding whether to transplant the organ. The index may be automatically generated and provided to the physician.

Normothermic perfusion may be preceded by and/or followed by hypothermic perfusion. In the hypothermic mode, the organ is perfused with a medical fluid containing substantially no oxygen, preferably a simple crystalloid solution that may preferably be augmented with antioxidants, intermittently or at a slow continuous flow rate. Hypothermic perfusion also can be performed in vivo as well as in vitro prior to removal of the organ from the donor. Hypothermic perfusion reduces the organ's metabolic rate, allowing the organ to be preserved for extended periods of time. The medical fluid is preferably fed into the organ by pressure from an intermediary tank which has a low pressure head so overpressurization of the organ is avoided. Alternatively, in embodiments, gravity can be used to feed the medical fluid into the organ from the intermediary tank, if appropriate. Alternatively, the organ may be perfused directly from a pump, such as a roller pump or a peristaltic pump, with proper pump control and/or sufficiently fail-safe controllers to prevent overpressurization of the organ, especially as a result of a system malfunction. Substantially eliminating overpressurization prevents or reduces damage to the vascular endothelial lining of the organ and to the organ tissue in general, in particular at hypothermic temperatures when the organ has less ability to protect itself by

vascular constriction. Viability of the organ may also be monitored, preferably automatically, during the recovery process, preferably by monitoring organ resistance (pressure/flow) and/or pH, pO₂, pCO₂, LDH, T/GST, Tprotein, lactate, glucose, base excess and/or ionized calcium levels in the medical fluid that has been perfused
5 through the organ and collected.

Embodiments of this invention include a control system for automatically controlling perfusion of one or more organs by selecting between perfusion modes and control parameters. Automatic perfusion may be based on sensed conditions in the system or manually input parameters. The system may be preprogrammed or
10 programmed during use. Default values and viability checks are utilized.

The perfusion apparatus may be used for various organs, such as the kidneys, and may be adapted to more complex organs, such as the liver, having multiple vasculature structures, for example, the hepatic and portal vasculatures of the liver.

An organ diagnostic apparatus may also be provided to produce diagnostic
15 data such as an organ viability index. The organ diagnostic apparatus includes features of an organ perfusion apparatus, such as sensors and temperature controllers, as well as cassette interface features, and provides analysis of input and output fluids in a perfusion system. Typically, the organ diagnostic apparatus is a simplified perfusion apparatus providing diagnostic data in a single pass, in-line perfusion.

20 The present invention also provides an organ cassette which allows an organ to be easily and safely moved between apparatus for perfusing, storing, analyzing and/or transporting the organ. The organ cassette may be configured to provide uninterrupted sterile conditions and efficient heat transfer during transport, recovery, analysis and storage, including transition between the transporter, the perfusion apparatus and the
25 organ diagnostic apparatus.

The present invention also provides an organ transporter which allows for transportation of an organ over long distances. The organ transporter may be used for various organs, such as the kidneys, and may be adapted to more complex organs, such as the liver, having multiple vasculature structures, for example, the hepatic and
30 portal vasculatures of the liver. The organ transporter includes features of an organ perfusion apparatus, such as sensors and temperature controllers, as well as cassette interface features.

The perfusion apparatus, transporter, cassette, and organ diagnostic apparatus may be networked to permit remote management, tracking and monitoring of the location and therapeutic and diagnostic parameters of the organ or organs being stored or transported. The information systems may be used to compile historical data of organ transport and storage, and provide cross-referencing with hospital and United Network for Organ Sharing (UNOS) data on the donor and recipient. The systems may also provide outcome data to allow for ready research of perfusion parameters and transplant outcomes.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other aspects and advantages of the invention will become apparent from the following detailed description of embodiments when taken in conjunction with the accompanying drawings, in which:

Fig. 1 is an organ perfusion apparatus according to the invention;

Fig. 2 is a schematic diagram of the apparatus of Fig. 1;

Fig. 3 is a diagram of the electronics of the apparatus of Fig. 1;

Fig. 4 is an exploded view of a first pump module of a combined pump, filtration, oxygenation and/or debubbler apparatus according to the invention;

Fig. 5 is an exploded view of a filtration module of a combined pump, filtration, oxygenation and/or debubbler apparatus according to the invention;

Fig. 6 is an exploded view of an oxygenation module of a combined pump, filtration, oxygenation and/or debubbler apparatus according to the invention;

Fig. 7 is an exploded view of a debubbler module of a combined pump, filtration, oxygenation and/or debubbler apparatus according to the invention;

Fig. 8 is an exploded view of a second pump module of a combined pump, filtration, oxygenation and/or debubbler apparatus according to the invention;

Fig. 9 is an exploded perspective view showing the modules of Figs. 4-8 assembled together;

Fig. 10 is a front perspective view of an assembled modular combined pump, filtration, oxygenation and/or debubbler apparatus according to the invention;

Figs. 11A - 11D show side perspective views of various embodiments of an organ cassette according to the invention;

Fig. 12 is a schematic diagram of an organ perfusion apparatus configured to simultaneously perfuse multiple organs;

Figs. 13A and 13B show a stepping motor/cam valve according to the invention;

Figs. 14A - 14F show another stepping motor/cam valve according to the invention;

5 Fig. 15 shows a block diagram that schematically illustrates a control system according to the invention;

Fig. 16 shows an exemplary diagram of possible processing steps according to the invention;

10 Figs. 17 and 17A show an embodiment of an organ cassette of the present invention;

Figs. 18 and 18A show an embodiment of an organ chair according to the present invention;

Fig. 19 shows an exterior perspective view of an organ transporter according to the present invention;

15 Fig. 20 shows a cross-section view of an organ transporter of Fig. 19;

Fig. 21 shows a block diagram of an organ transporter of Fig. 19;

Fig. 22 shows operation states of an organ transporter of Fig. 19;

Fig. 23 shows an alternative cross-section view of an organ transporter of Fig. 19;

20 Fig. 24 shows data structures and information transfer schemes of a perfusion and organ transplant system of the present invention;

Figs. 25 and 25A show motor control of a perfusion pump according to the present invention;

25 Fig. 26 shows a liver perfusion apparatus according to the present invention;

Fig. 27 shows a close-up view of a peristaltic pump for use in a perfusion apparatus according to Fig. 26;

Fig. 28 shows an overall view of an organ diagnostic system according to the present invention;

30 Fig. 29 shows a perspective view of an organ evaluation instrument for use in an organ diagnostic system according to Fig. 28;

Fig. 30 shows an in-line perfusion system for use in an organ diagnostic system according to Fig. 28; and

Fig 31 shows a logic circuit for an organ diagnostic system according to Fig. 28.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

For a general understanding of the features of the invention, reference is made to the drawings. In the drawings, like reference numerals have been used throughout to designate like elements.

Figure 1 shows an organ perfusion apparatus 1 according to the invention. Figure 2 is a schematic illustration of the apparatus of Fig. 1. The apparatus 1 is preferably at least partially microprocessor controlled, and pneumatically actuated. The microprocessor 150 connection to the sensors, valves, thermoelectric units and pumps of the apparatus 1 is schematically shown in Fig. 3. Microprocessor 150 and apparatus 1 may be configured to and are preferably capable of further being connected to a computer network to provide data sharing, for example across a local area network or across the Internet.

The organ perfusion apparatus 1 is capable of perfusing one or more organs simultaneously, at both normothermic and hypothermic temperatures (hereinafter, normothermic and hypothermic perfusion modes). All medical fluid contact surfaces are preferably formed of or coated with materials compatible with the medical fluid used, more preferably non-thrombogenic materials. As shown in Fig. 1, the apparatus 1 includes a housing 2 which includes front cover 4, which is preferably translucent, and a reservoir access door 3. The apparatus preferably has one or more control and display areas 5a, 5b, 5c, 5d for monitoring and controlling perfusion.

As schematically shown in Fig. 2, enclosed within the housing 2 is a reservoir 10 which preferably includes three reservoir tanks 15a, 15b, 17. Two of the reservoir tanks 15a, 15b are preferably standard one liter infusion bags, each with a respective pressure cuff 16a, 16b. A pressure source 20 can be provided for pressurizing the pressure cuffs 16a, 16b. The pressure source 20 is preferably pneumatic and may be an on board compressor unit 21 supplying at least 10 LPM external cuff activation via gas tubes 26, 26a, 26b, as shown in Fig. 2. The invention, however, is not limited to use of an on board compressor unit as any adequate pressure source can be employed, for example, a compressed gas (e.g., air, CO₂, oxygen, nitrogen, etc.) tank (not shown) preferably with a tank volume of 1.5 liters at 100 psi or greater for internal pressurization. Alternatively, an internally pressurized reservoir tank (not shown)

may be used. Reservoir tanks 15a, 15b, 17 may, in embodiments, be bottles or other suitably rigid reservoirs that can supply perfusate by gravity or can be pressurized by compressed gas.

Gas valves 22-23 are provided on the gas tube 26 to allow for control of the pressure provided by the onboard compressor unit 21. Anti-back flow valves 24a, 24b may be provided respectively on the gas tubes 26a, 26b. Pressure sensors P5, P6 may be provided respectively on the gas tubes 26a, 26b to relay conditions therein to the microprocessor 150, shown in Fig. 3. Perfusion, diagnostic and/or transporter apparatus may be provided with sensors to monitor perfusion fluid pressure and flow in the particular apparatus to detect faults in the particular apparatus, such as pressure elevated above a suitable level for maintenance of the organ. Gas valves GV₁ and GV₂ may be provided to release pressure from the cuffs 16a, 16b. One or both of gas valves GV₁ and GV₂ may be vented to the atmosphere. Gas valve GV₄ in communication with reservoir tanks 15a, 15b via tubing 18a, 18b may be provided to vent air from the reservoir tanks 15a, 15b through tubing 18. Tubing 18, 18a, 18b, 26, 26a and/or 26b may be configured with filters and/or check valves to prevent biological materials from entering the tubing or from proceeding further along the fluid path. The check valves and/or filters may be used to prevent biological materials from leaving one organ perfusion tubeset and being transferred to the tubeset of a subsequent organ in a multiple organ perfusion configuration. The check valves and/or filters may also be used to prevent biological materials, such as bacteria and viruses, from being transferred from organ to organ in subsequent uses of the perfusion apparatus in the event that such biological materials remain in the perfusion apparatus after use. The check valves and/or filters prevent contamination problems associated with reflux in the gas and/or vent lines. For example, the valves may be configured as anti-reflux valves to prevent reflux. The third reservoir tank 17 is preferably pressurized by pressure released from one of the pressure cuffs via gas valve GV₂.

The medical fluid is preferably synthetic and may, for example, be a simple crystalloid solution, or may be augmented with an appropriate oxygen carrier. The oxygen carrier may, for example, be washed, stabilized red blood cells, cross-linked hemoglobin, pegolated hemoglobin or fluorocarbon based emulsions. The medical fluid may also contain antioxidants known to reduce peroxidation or free radical

damage in the physiological environment and specific agents known to aid in tissue protection. As discussed in detail below, an oxygenated (e.g., cross-linked hemoglobin-based bicarbonate) solution is preferred for the normothermic mode while a non-oxygenated (e.g., simple crystalloid solution preferably augmented with
5 antioxidants) solution is preferred for the hypothermic mode. The specific medical fluids used in both the normothermic and hypothermic modes are designed to reduce or prevent the washing away of or damage to the vascular endothelial lining of the organ. For the hypothermic perfusion mode, as well as for flush and/or static storage, a preferred solution is the solution disclosed in U.S. Patent Application No.
10 09/628,311, filed July 28, 2000, the entire disclosure of which is incorporated herein by reference. Examples of additives which may be used in perfusion solutions for the present invention are also disclosed in U.S. Patent No. 6,046,046 to Hassanein, the entire disclosure of which is incorporated by reference. Of course, other suitable solutions and materials may be used, as is known in the art.

15 The perfusion solution may be provided in a perfusion solution kit, for example, a saleable package preferably containing at least one first container holding a first perfusion solution for normothermic perfusion and at least one second container holding a second, different perfusion solution for hypothermic perfusion, optionally
the box 10 shown in Fig. 2. The first perfusion solution may contain at least one
20 oxygen carrier, may be oxygenated and/or may be selected from the group consisting of a cross-linked hemoglobin and stabilized red blood cells. The second perfusion solution may be non-oxygenated, may contain at least one anti-oxidant, and/or may contain at least one vasodilator. Additionally, the solution preferably contains no more than 5 mM of dissolved pyruvate salt. Also, the first container and the second
25 container may be configured to be operably connected to a perfusion machine as perfusion fluid reservoirs in fluid communication with perfusate conduits of said perfusion machine. Further, one of the first and second containers may be compressible to apply pressure to the perfusion solution therein. Furthermore, at least one of the first and second containers may include a first opening for passage of a
30 contained perfusion solution out of the container and a second opening passage of a compressed gas into the container. The package may be a cassette configured to be operably connected to a perfusion machine for connection of the first and second

containers within the cassette in fluid communication with perfusate conduits or tubing of the perfusion machine.

5 In other embodiments, the perfusion solution kit may contain at least one first container holding a first perfusion solution for hypothermic perfusion at a first temperature and at least one second container holding a second, different perfusion solution for hypothermic perfusion at a second temperature lower than the first temperature. In the kit, the first perfusion solution may contain at least a crystalloid and may contain at least one vasodilator. The second perfusion solution may be oxygen carrier enhanced, where the oxygen carrier is selected from the group consisting of a hemoglobin and stabilized red blood cells. In addition, the second perfusion solution may, if desired, contain at least one anti-oxidant or free radical scavenger. Preferably, the second solution contains no more than 5 mM of dissolved pyruvate salt. As above, the first container and the second container may be configured to be operably connected to a perfusion machine as perfusion fluid reservoirs in fluid communication with perfusate conduits of said perfusion machine. Further, one of the first and second containers may be compressible to apply pressure to the perfusion solution therein. Furthermore, at least one of the first and second containers may include a first opening for passage of a contained perfusion solution out of the container and a second opening passage of a compressed gas into the container. The package may be a cassette configured to be operably connected to a perfusion machine for connection of the first and second containers within the cassette in fluid communication with perfusate conduits or tubing of the perfusion machine.

15 The medical fluid within reservoir 10 is preferably brought to a predetermined temperature by a first thermoelectric unit 30a in heat transfer communication with the reservoir 10. A temperature sensor T3 relays the temperature within the reservoir 10 to the microprocessor 150, which adjusts the thermoelectric unit 30a to maintain a desired temperature within the reservoir 10 and/or displays the temperature on a control and display areas 5a for manual adjustment. Alternatively or in addition, and preferably where the organ perfusion device is going to be transported, the medical fluid within the hypothermic perfusion fluid reservoir can be cooled utilizing a cryogenic fluid heat exchanger apparatus such as that disclosed in co-pending application Serial No. 09/039,443, which is hereby incorporated by reference.

An organ chamber 40 is provided which supports a cassette 65, as shown in Fig. 2, which holds an organ to be perfused, or a plurality of cassettes 65, 65, 65, as shown in Fig. 12, preferably disposed one adjacent the other. Various embodiments of the cassette 65 are shown in Figs. 11A-11D. The cassette 65 is preferably formed of a material that is light but durable so that the cassette 65 is highly portable. The material may also be transparent to allow visual inspection of the organ.

Preferably the cassette 65 includes side walls 67a, a bottom wall 67b and an organ supporting surface 66, which is preferably formed of a porous or mesh material to allow fluids to pass therethrough. The cassette 65 may also include a top 67d and may be provided with an opening(s) 63 for tubing (see, for example, Fig. 11D). The opening(s) 63 may include seals 63a (e.g., septum seals or o-ring seals) and optionally be provided with plugs (not shown) to prevent contamination of the organ and maintain a sterile environment. Also, the cassette 65 may be provided with a closeable air vent 61 (see, for example, Fig. 11D). Additionally, the cassette 65 may be provided with tubing for connection to the organ or to remove medical fluid from the organ bath and a connection device(s) 64 for connecting the tubing to, for example, tubing 50c, 81, 82, 91 and/or 132 (see, for example, Fig. 11D). The cassette 65, and more particularly the organ support, opening(s), tubing(s) and/or connection(s), may be specifically tailored to the type of organ and/or size of organ to be perfused. Outer edges 67c of the side support walls 67a can be used to support the cassette 65 disposed in the organ chamber 40. The cassette 65 may further include a handle portion 68 which allows the cassette 65 to be easily handled, as shown, for example, in Figs. 11C and 11D. Each cassette 65 may also be provided with its own stepping motor/cam valve 75 (for example, in the handle portion 68, as shown in Fig. 11C) for fine tuning the pressure of medical fluid perfused into the organ 60 disposed therein, discussed in more detail below. Alternatively, pressure may, in embodiments, be controlled by way of a pneumatic chamber, such as an individual pneumatic chamber for each organ (not shown), or by any suitable variable valve such as a rotary screw valve or a helical screw valve.

Fig. 17 shows an alternative embodiment of cassette 65. In Fig. 17, cassette 65 is shown with tubeset 400. Tubeset 400 can be connected to perfusion apparatus 1 or to an organ transporter or an organ diagnostic apparatus, and allows cassette 65 to be moved between various apparatus without jeopardizing the sterility of the interior of cassette 65. Preferably, cassette 65 is made of a sufficiently durable material that it can

withstand penetration and harsh impact. Cassette 65 is provided with a lid, preferably two lids, an inner lid 410 and an outer lid 420. The lids 410 and 420 may be removable or may be hinged or otherwise connected to the body of cassette 65. Clasp 405 provides a mechanism to secure lids 410 and 420 to the top of cassette 65. Clasp 405 may additionally be configured with a lock to provide further security and stability. A biopsy port 430 may additionally be included in inner lid 410 or both inner lid 410 and outer lid 420. Biopsy port 430 provides access to the organ to allow for additional diagnosis of the organ with minimal disturbance of the organ. Cassette 65 may also have an overflow trough 440 (shown in Fig. 17A). Overflow trough 440 is a channel present in the top of cassette 65. When lids 410 and 420 are secured on cassette 65, overflow trough 440 provides a region that is easy to check to determine if the inner seal is leaking. Perfusate may be poured into and out of cassette 65 and may be drained from cassette 65 through a stopcock or removable plug.

Cassette 65 and/or both lids 410 and 420 may be constructed of an optically clear material to allow for viewing of the interior of cassette 65 and monitoring of the organ and to allow for video images or photographs to be taken of the organ. Perfusion apparatus 1 or cassette 65 may be wired and fitted with a video camera or a photographic camera, digital or otherwise, to record the progress and status of the organ. The captured images may be made available over a computer network such as a local area network or the Internet to provide for additional data analysis and remote monitoring. Cassette 65 may also be provided with a tag that would signal, e.g., through a bar code, magnetism, radio frequency, or other means, the location of the cassette, that the cassette is in the apparatus, and/or the identity of the organ to the perfusion apparatus or transporter. Cassette 65 may be sterile packaged and/or may be packaged or sold as a single-use disposable cassette, such as in a peel-open pouch. A single-use package containing cassette 65 may also include tubeset 400.

Cassette 65 may additionally be provided with an organ chair 1800 shown in Figs. 18 and 18A. Organ chair 1800 is removable and provides a support surface for the organ within cassette 65. Utilizing a removable organ chair 1800 allows the organ to be cannulated and secured under cold conditions when the organ is recovered from a donor before being placed into cassette 65. Organ chair 1800 may be reusable or single-use. Organ chair 1800 may be constructed specifically to correspond to each type of organ,

such as the kidney, heart or liver. Organ chair 1800 is preferably designed to be form fitting to the organ but to allow for the full anthropometric range of organ sizes.

Preferably, organ chair 1800 is at least partially perforated to allow fluids to pass through organ chair 1800. The perforations in organ chair 1800 may be sized to catch organ debris, or an additional filter layer, preferably constructed of cloth, fabric, nylon, plastic, etc., to catch organ debris of at least 15 microns in diameter. In addition, a separate filter may be used on the tubing that intakes fluid directly from the perfusate bath to prevent organ debris of a predetermined size, for example at least 10 to 15 microns in diameter, from entering the perfusion tubing.

Organ chair 1800 may also be configured with a venous outflow sampler 1810. Organ chair 1800 funnels the venous outflow into venous outflow sampler 1810. Venous outflow sampler 1810 provides a readily available source for capturing the venous outflow of the organ. Capturing the venous outflow in this manner permits analysis of the perfusate leaving the organ without cannulating a vein and enables organ viability to be measured with a high degree of sensitivity by analyzing differentially the perfusate flowing into and out of the organ. Alternatively, venous outflow may be captured directly by cannulating a vein, but this method increases the risk of damaging the vein or the organ. Organ chair 1800 may also be raised and lowered within cassette 65 to facilitate sampling from venous outflow sampler 1810. Alternatively, a sufficient amount of the organ bath may be drained from cassette 65 to obtain access to venous outflow sampler 1810 or to capture venous outflow before the outflow mixes with the rest of the perfusate in the organ bath.

Organ chair 1800 is preferably additionally configured with a cannula 1820 that attaches to the perfused artery, such as the renal artery. Cannula 1820 may be reusable or may be suitable for single-use, preferably provided in a sterile package with cassette 65, organ chair 1800 and tubeset 400. Cannula 1820 is provided with a cannula clamp 1830 to secure cannula 1820 around the perfused artery and to preferably provide leak-tight perfusion. A straight-in flanged cannula may also be used, however clamping around the artery is preferable to prevent contact with the inner surface of the artery, which is easily damaged. Cannula 1820 may also be configured with additional branching connections for accessory arteries. Multiple cannula and cannula clamp sizes may be used to accommodate various artery sizes or an adjustable cannula and cannula clamp may be used to accommodate various sized arteries. Cannula clamp 1830 may be

a clam-shell configuration or may be a two-part design. Cannula clamp 1830 may be configured with integral or separate means for tightening cannula clamp 1830 to the proper pressure to provide leak-tight perfusion. In addition, cannula 1820 may be provided with a snap 1840 to hold cannula 1820 closed. Cannula 1820 may also be
5 provided with a vent 1850 to remove air bubbles from cannula 1820.

Organ chair 1800 preferably has a detented region 1860 that corresponds to protrusions 1870 on cannula 1820. Such detents, tracks or grooves on organ chair 1800 allow cannula 1820 to be positioned at several locations to provide various tensions on the perfused artery. This allows the ideal minimum tension to be set for each artery.
10 Cannula clamp 1830 secures the perfusate tubing to the perfused artery. Cannula 1820 is adjustably secured to organ chair 1800 to provide for positioning the perfused artery to accommodate variations in organ size and artery length to prevent stretching, twisting, sagging or kinking of the artery. The combination of organ chair 1800, cannula 1820 and additional straps or wide belts provides a secure platform to transport the organ and
15 to transfer the organ between the cassette and the surgical field.

Organ chair 1800, cannula 1820 and/or cannula clamp 1830 may be constructed of an optically clear material to facilitate monitoring of the organ and perfusion status.

The cassette 65 is configured such that it may be removed from the organ perfusion apparatus 1 and transported to another organ perfusion apparatus in a portable transporter apparatus, such as, for example, a conventional cooler or a portable container
20 such as that disclosed in simultaneously filed co-pending U.S. Application No. 09/161,919, or U.S. Patent No. 5,586,438 to Fahy, which are hereby incorporated by reference in their entirety.

In embodiments, when transported, the organ is disposed on the organ supporting surface 66 and the cassette 65 is preferably enclosed in a preferably sterile
25 bag 69, as shown, for example, in Fig. 11A. When the organ is perfused with medical fluid, effluent medical fluid collects in the bag 69 to form an organ bath. Alternatively, the cassette 65 can be formed with a fluid tight lower portion in which the effluent medical fluid may collect, or the effluent medical fluid may collect in the organ chamber
30 40 to form the organ bath. In either alternative case, the bag 69 would preferably be removed prior to inserting the cassette into the organ chamber 40. Further, where a plurality of organs are to be perfused, an organ chamber may be provided for each organ.

Alternatively, cassette 65 can be transported in the dual-lid cassette of Fig. 17 and additionally carried within a portable organ transporter.

Fig. 19 shows an external view of an embodiment of transporter 1900 of the invention. The transporter 1900 of Fig. 19 has a stable base to facilitate an upright position and handles 1910 for carrying transporter 1900. Transporter 1900 may also be fitted with a shoulder strap and/or wheels to assist in carrying transporter 1900. A control panel 1920 is preferably also provided. Control panel 1920 may display characteristics, such as, but not limited to infusion pressure, power on/off, error or fault condition, flow rate, flow resistance, infusion temperature, bath temperature, pumping time, battery charge, temperature profile (maximums and minimums), cover open or closed, history log or graph, and additional status details and messages, which are preferably further transmittable to a remote location for data storage and/or analysis. Flow and pressure sensors or transducers in transporter 1900 may be used to calculate various organ characteristics including pump pressure and vascular resistance of an organ, which can be stored in computer memory to allow for analysis of, for example, vascular resistance history, as well as to detect faults in the apparatus, such as elevated pressure.

Transporter 1900 has latches 1930 that require positive user action to open, thus avoiding the possibility that transporter 1900 inadvertently opens during transport. Latches 1930 hold top 1940 in place on transporter 1900. Top 1940 or a portion thereof may be constructed with an optically clear material to provide for viewing of the cassette and organ perfusion status. Transporter 1900 may be configured with a cover open detector that monitors and displays if the cover is open or closed. Transporter 1900 may be configured with an insulating exterior of various thicknesses to allow the user to configure transporter 1900 for varying extents and distances of transport. In embodiments, compartment 1950 may be provided to hold patient and organ data such as charts, testing supplies, additional batteries, hand-held computing devices and/or other accessories for use with transporter 1900. Transporter 1900 may also be configured with means for displaying a UNOS label and/or identification and return shipping information.

Fig. 20 shows a cross-section view of a transporter 1900. Transporter 1900 contains cassette 65 and pump 2010. Cassette 65 may be placed into and taken out of transporter 1900 without disconnecting tubeset 400 from cassette 65, thus maintaining

sterility of the organ. Sensors in transporter 1900 can detect the presence of cassette 65 in transporter 1900, and depending on the sensor, can read the organ identity from a barcode or radio frequency or other smart tag that may be integral to cassette 65. This allows for automated identification and tracking of the organ and helps monitor and control the chain of custody. A global positioning system may be added to transporter 1900 and/or cassette 65 to facilitate tracking of the organ. Transporter 1900 can be interfaced to a computer network by hardwire connection to a local area network or by wireless communication while in transit. This interface allows perfusion parameters, vascular resistance, and organ identification and transporter and cassette location to be tracked and displayed in real-time or captured for future analysis.

Transporter 1900 also preferably contains a filter 2020 to remove sediment and other particulate matter, preferably ranging in size from 0.05 to 15 microns in diameter or larger, from the perfusate to prevent clogging of the apparatus or the organ. Transporter 1900 also contains batteries 2030, which may be located at the bottom of transporter 1900 or beneath pump 2010 or at any other location that provides easy access to change batteries 2030. Batteries 2030 may be rechargeable outside of transporter 1900 or while intact within transporter 1900 and/or are preferably hot-swappable one at a time. Batteries 2030 are preferably rechargeable rapidly and without full discharge. Transporter 1900 may also provide an additional storage space 2040 at the bottom of transporter 1900 for power cords, batteries and other accessories. Transporter 1900 may also include a power port for a DC hookup to a vehicle such as an automobile or airplane and/or for an AC hookup.

Fig. 21 shows a block diagram of transporter 1900. Transporter 1900 of Fig. 21 is intended to provide primarily hypothermic perfusion, and may operate at any temperatures, for example in the range of -25 to 60° C, approximately 0 to 8° C, preferably approximately 4° C. The temperature may be adjusted based on the particular fluids used and adapted to the particular transport details, such as length of time of transport. Transporter 1900 is cooled by coolant 2110, which may be an ice and water bath or a cryogenic material. In embodiments using cryogenic materials, the design should be such that organ freezing is prevented. The temperature of the perfusate bath surrounding the organ is monitored by temperature transducer 2115. Transporter 1900 also contains filters 2020 to remove sediment and particulate, ranging in size from 0.05 to 15 microns in diameter or larger, from the perfusate to prevent clogging of the

apparatus or the organ. Using a filter 2020 downstream of pump 2010 allows for capturing inadvertent pump debris and also dampens pressure spikes from pump 2010.

The flow of perfusate within transporter 1900 is controlled by pump 2010, which is preferably a peristaltic or roller pump. Pump 2010 is preferably not in contact with the perfusate to help maintain sterility. In addition, tubeset 400 may be attached to pump 2010 without opening the tubing circuit. Pump 2010 is controlled by a computer or microcontroller. The computer can actively modulate the angular velocity of pump 2010 to reduce the natural pulse actions of pump 2010 to a low level, resulting in essentially non-pulsatile flow. Further computer control can impose a synthesized pressure pulse profile that can be sinusoidal or physiological or otherwise. The average flow rate and pressure can be made independent of pulse repetition rate by pulse width modulating or amplitude modulating the synthesized pressure pulses. Control over some or all of the pulse parameters can be made available to users through control panel 1920 or over a network. Pulse control can be organ specific. In the case of a liver, a single pump can provide continuous flow to the portal vein at, for example, 1 to 3 liters per minute while providing pulsatile flow to the hepatic artery at, for example, 100 to 300 ml per minute. Synchronizing the shunt valves to the pump controller allows independent pressure regulation of the two flows.

The flow of the perfusate into the organ is monitored by flow sensor 2125. Pressure transducers 2120 may be present to monitor the pressure the perfusate places on the tubing. Pressure transducers 2120 may be used to monitor the pump pressure and/or the infusion pressure. A pressure transducer 2120 may be present just upstream of the organ to monitor the organ infusion pressure. Transporter 1900 may be configured with a bubble detector 2125 to detect bubbles before the perfusate enters bubble trap 2130. Bubble detectors, such as bubble detector 2125, may be used to detect bubbles in, for example, the infuse line and/or in the pump output line. Bubble trap 2130 removes air bubbles from the perfusate and vents the bubbles into the wash tube. Bubble trap 2130 may be disposable and may be constructed integral to tubeset 400. Perfusate exiting bubble trap 2130 can either continue through infuse valve 2140 or wash valve 2150. Wash valve 2150 is normally open and infuse valve 2140 is normally closed. Preferably, wash valve 2150 and infuse valve 2140 operate dependently in an on/off manner, such that if one valve is open, the other valve is closed. Although infuse valve 2140 is normally closed, if the sensor and monitors all report suitable perfusion

parameters present in transporter 1900, then infuse valve 2140 may be opened to allow organ perfusion. In the occurrence of a fault, such as elevated perfusion pressure above a suitable level for the organ, infuse valve 2140 switches back to closed and wash valve 2150 is opened to divert fluid flow into the perfusate bath surrounding the organ. This provides a failsafe mechanism that automatically shunts perfusate flow and prevents organ perfusion in case of a power failure or computer or electronics malfunction. A pressure transducer 2120, such as designated by P_2 , may be hardwired, redundant to the computer and software control, to wash valve 2150 and infuse valve 2140 to quickly deliver a default message to the valves in the case of a pressure malfunction. In embodiments, the diverted fluid may be separately collected in another container or compartment.

Fig. 22 shows various operation states of transporter 1900. For example, using the controls provided on control panel 1920, a user may select operations such as perfuse, idle, wash and prime. Fig. 22 shows various options depending on the present state of transporter 1900. The labels idle, prime, wash, perfuse and error handling indicate the state of transporter 1900 that is preferably displayed on control panel 1920 during the corresponding operation. For example, when transporter 1900 is in a wash operation, control panel 1920 displays the wash operation indicator, such as an LED display. The arrows connecting the various operations of transporter 1900 indicate the manual and automatic actions that may occur to transition transporter 1900 between operation states. Manual actions require the user to act, for example by pressing a button or turning a knob or dial. Fig. 22 exemplifies pressing a button or other indicator, for example, to move from a perfusion operation to an idle operation by pressing the stop button (Press Stop). To move directly into a perfuse operation from an idle operation, a user presses the perfuse button (Press Perfuse).

Automatic operations may be controlled by the passage of time and/or by an internal monitor within transporter 1900. Such automatic operation is shown in Fig. 22, for example, connecting the prime operation to the idle operation. If the prime operation has been completed according to the internal transporter program parameters before the wash button has been pressed, transporter 1900 returns to an idle operation. Another automatic operation occurs during a perfuse operation if a fault or error occurs, such as overpressurization of the organ. When an error or fault occurs, transporter 1900 can move to an error handling operation to determine the extent or degree of the fault or

error. If the fault or error is determined to be a small or correctable error, transporter 1900 moves into a wash operation. If transporter 1900 can then adjust the system parameters to handle the fault or error, transporter 1900 moves back to perfuse (Error Recovery). If transporter 1900 can not adjust the system parameters to handle the fault or error, transporter 1900 moves to an idle operation. If the error or fault detected is determined to be substantial, transporter 1900 may move directly into an idle operation.

Fig. 23 shows an alternative cross-section of transporter 1900. Transporter 1900 may have an outer enclosure 2310 constructed of metal, or preferably a plastic or synthetic resin that is sufficiently strong to withstand penetration and impact.

Transporter 1900 contains insulation 2320, preferably a thermal insulation made of, for example, glass wool or expanded polystyrene. Insulation 2320 may be various thicknesses ranging from 0.5 inches to 5 inches thick or more, preferably 1 to 3 inches, such as approximately 2 inches thick. Transporter 1900 is cooled by coolant 2110, which may be, e.g., an ice and water bath or a cryogenic material. In embodiments using cryogenic materials, the design should be such that organ freezing is prevented. An ice and water mixture is preferably in an initial mixture of approximately 1 to 1, however, in embodiments the ice and water bath may be frozen solid. Transporter 1900 can be configured to hold various amounts of coolant, preferably up to 10 to 12 liters. An ice and water bath is preferable because it is inexpensive and can not get cold enough to freeze the organ. Coolant 2110 preferably lasts for a minimum of 6 to 12 hours and more preferably lasts for a minimum of 30 to 50 hours without changing coolant 2110. The level of coolant 2110 may be viewed through a transparent region of transporter 1900 or may be automatically detected and monitored by a sensor. Coolant 2110 can be replaced without stopping perfusion or removing cassette 65 from transporter 1900. Coolant 2110 is maintained in a watertight compartment 2115 of transporter 1900. Compartment 2115 prevents the loss of coolant 2110 in the event transporter 1900 is tipped or inverted. Heat is conducted from the walls of the perfusion reservoir and cassette 65 into coolant 2110 enabling control within the desired temperature range. Coolant 2110 is a failsafe cooling mechanism because transporter 1900 automatically reverts to cold storage in the case of power loss or electrical or computer malfunction. Transporter 1900 may also be configured with a heater to raise the temperature of the perfusate.

Transporter 1900 may be powered by batteries or by electric power provided through plug 2330. An electronics module 2335 is also provided in transporter 1900. Electronics module 2335 is cooled by vented air convection 2370, and may further be cooled by a fan. Preferably, electronic module 2335 is positioned separate from the perfusion tubes to prevent the perfusate from wetting electronics module 2335 and to avoid adding extraneous heat from electronics module 2335 to the perfusate. Transporter 1900 has a pump 2010 that provides pressure to perfusate tubing 2360 to deliver perfusate 2340 to organ 2350. Transporter 1900 may be used to perfuse various organs such as a kidney, heart, liver, small intestine and lung. Transporter 1900 and cassette 65 may accommodate various amounts of perfusate 2340, for example up to 3 to 5 liters. Preferably, approximately 1 liter of a hypothermic perfusate 2340 is used to perfuse organ 2350. Organ 2350 may be various organs, including but not limited to a kidney, heart, lung, liver or small intestine.

Cassette 65 and transporter 1900 are preferably constructed to fit or mate such that efficient heat transfer is enabled. The geometric elements of cassette 65 and transporter 1900 are preferably constructed such that when cassette 65 is placed within transporter 1900, the elements are secure for transport.

Fig. 24 shows various data structures and information connections that can be facilitated to assist in the overall communication and data transfers that may be beneficial before, during and after organ transplantation. The perfusion apparatus, transporter, cassette, and organ diagnostic apparatus may be networked to permit remote management, tracking and monitoring of the location and therapeutic and diagnostic parameters of the organ or organs being stored or transported. The information systems may be used to compile historical data of organ transport and storage, and provide cross-referencing with hospital and UNOS data on the donor and recipient. The systems may also provide outcome data to allow for ready research of perfusion parameters and transplant outcomes. For example, information regarding the donor may be entered at the location where an organ is recovered from a donor. Information may also be directly recovered from the perfusion, diagnostic or transporter apparatus to monitor organ status and location. Various types of information may be grouped into sub-records or sub-directories to assist in data management and transfer. All the sub-records may be combined to form an overall

transplant record, which may be disseminated to or retrievable by physicians, scientists or other organizations for tracking and monitoring purposes.

Preferred embodiments of transporter 1900 can automatically log much or all of the perfusion process data and transporter 1900 events into an internal database. A
5 radio frequency or barcode labeled tag or the like for each cassette 65 allows transporter 1900 to reference the data uniquely to each organ. When transporter 1900 reaches a docking port, transporter 1900 can upload data to a main database computer over a LAN. Transporter 1900 can also provide real-time status whenever transporter 1900 is connected to the LAN. Transporter 1900 can also be configured with a
10 wireless communications setup to provide real-time data transfer during transport. Perfusion apparatus 1 can also be connected to the LAN and since perfusion apparatus is generally stationary, data uploads can occur continuously and in real-time. The data can be cross-referenced with UNOS data to utilize the UNOS data on organ identification, donor condition, donor logistics, recipient logistics and recipient
15 outcomes. Data may be displayed and accessed on the Internet to facilitate monitoring from any location.

Within the perfusion, diagnostic and/or transporter apparatus, the organ bath is preferably cooled to a predetermined temperature by a second thermoelectric unit 30b, as shown in Fig. 2, in heat transfer communication with the organ chamber 40.
20 Alternatively and preferably where the organ perfusion device is going to be transported, the medical fluid within reservoir 10 can be cooled utilizing a heat transfer device such as an ice and water bath or a cryogenic fluid heat exchanger apparatus such as that disclosed in co-pending Application No. 09/039,443, which is hereby incorporated by reference. A temperature sensor T2 within the organ chamber
25 40 relays the temperature of the organ 60 to the microprocessor 150, which adjusts the thermoelectric unit 30b to maintain a desired organ temperature and/or displays the temperature on the control and display areas 5c for manual adjustment.

Medical fluid may be fed from the bag 15a directly to an organ 60 disposed in the organ chamber 40 through tubing 50a, 50b, 50c or from bag 15b through tubing
30 50d, 50e, 50c by opening valve LV₄ or LV₃, respectively. Conventional medical fluid bag and tubing connections may be utilized. All tubing is preferably disposable, easily replaceable and interchangeable. Further, all tubing is preferably formed of or coated with materials compatible with the medical fluids used, more preferably non-

thrombogenic materials. An end of the tubing 50c is inserted into the organ 60. The tubing may be connected to the organ(s) with conventional methods, for example, with sutures. The tubing may include a lip to facilitate connection to the organ.

Alternatively, cannula 1820 described above may be used with or without connection to an organ chair 1800. However, the specific methods and connection depend on the type of organs(s) to be perfused.

The microprocessor 150 preferably controls the pressure source 20 in response to signals from the pressure sensor P1 to control the pressure of the medical fluid fed into the organ 60. The microprocessor 150 may display the pressure on the control and display areas 5a, optionally for manual adjustment. A fluid flow monitor F1 may also be provided on the tubing 50c to monitor the flow of medical fluid entering the organ 60 to indicate, for example, whether there are any leaks present in the organ.

Alternatively, the medical fluid may be fed from the reservoir tank 17 via tubing 51 into an intermediary tank 70 preferably having a pressure head of approximately 5 to 40 mm Hg. Medical fluid is then fed by gravity or, preferably, pressure, from the intermediary tank 70 to the organ 60 along tubing 50c by activating a valve LV₆. A level sensor 71 may be provided in the intermediary tank 70 in order to maintain the pressure head. Where a plurality of organ chambers 40 and organs 60 are provided, the organs 60 are connected in parallel to the reservoir 10 utilizing suitable tubing duplicative of that shown in Fig. 2. See, for example, Fig. 12. The use of pneumatically pressurized and gravity fed fluid pumps configured to avoid overpressurization even in cases of system failure reduces or prevents general tissue damage to the organ and the washing away of or damage to the vascular endothelial lining of the organ. Thus, organ perfusion in this system can be performed, e.g., with either hydrostatic perfusion (gravity or pressure fed flow) or peristaltic perfusion by introducing flow to the organ from a peristaltic (roller) pump.

A bubble detection system may be installed to sense bubbles in the perfusate. An air sensor and sensor board are preferably used. The output of the sensor activates a debubbler system, such as an open solenoid valve, to rid bubbles from the perfusate flow prior to organ introduction. As with all of the sensors and detectors in this system, the bubble detector may be positioned at any point in the system that is effective based on the particular parameters or design characteristics of the system.

For example, a bubble detector and debubbler system BD may be positioned between the cam valve 205 and pressure sensor P1, as shown in Fig. 1.

5 A stepping motor/cam valve 205, or other suitable variable valve such as a rotary screw valve, may be arranged on the tubing 50c to provide pulsatile delivery of the medical fluid to the organ 60, to decrease the pressure of the medical fluid fed into the organ 60, and/or to stop flow of medical fluid into the organ 60 if the perfusion pressure exceeds a predetermined amount. Alternatively, a flow diverter or shunt line may be provided in the perfusion apparatus to which the fluid flow is diverted in the occurrence of a fault, such as excess pressure, for example by opening and closing a valve or a series of valves. Specific embodiments of the stepping motor/cam valve are shown in Figs. 13A-13B and 14A-14F. Figs. 13A-13B show a stepping motor/rotational type cam valve.

10 Fig. 13A is a top view of the apparatus. Tubing, for example, tubing 50c, is interposed between a support 203 and cam 200. Cam 200 is connected by a rod 201 to stepping motor 202. Fig. 13B is a side view of the apparatus. The dashed line shows the rotational span of the cam 200. In Fig. 13B, the cam 200 is in its non-occluding position. Rotated 180 degrees, the cam 200 totally occludes the tubing 50c with varying degrees of occlusion therebetween. This stepping motor/cam valve is relatively fast, for example, with respect to the embodiment shown in Figs. 14A - 14F; however, it requires a strong stepping motor.

20 Figs. 14A - 14F disclose another stepping motor/cam valve 210 according to the invention. Fig. 14A is a side view of the apparatus while Fig. 14C is a top view. Tubing, for example, tubing 50c, is interposed between cam 220 and support 223. The cam 220 is connected to stepping motor 222 by supports 221a - 221d and helical screw 225, which is connected to the stepping motor 222 via plate 222a. Fig. 14B shows the supports 221a and plate 222a in front view. As shown in Fig. 14D, where the support 221d is to the left of the center of the helical screw 225, the tubing 50c is not occluded. However, as the helical screw 225 is turned by the stepping motor 222, the support 221d moves to the left (with respect to Figs. 14D - 14F) toward a position where the cam 220 partially or fully occludes the tubing 50c. Such apparatus is slower than the apparatus of Figs. 13A - 13B, but is more energy efficient.

30 Medical fluid expelled from the organ 60 which has collected in the bottom of the bag 69 (the cassette 65 or the organ chamber 40) is either pumped out through

tubing 81 by a pump 80 for filtration, passing through a filter unit 82 and being returned to the organ bath, or is pumped out by a pump 90 for circulation through tubing 91. The pumps 80, 90 are preferably conventional roller pumps or peristaltic pumps; however, other types of pumps may also be appropriate.

5 Fig. 25 shows a simplified schematic of a pump and pulse controller 2500 and the interaction of the pump and pulse controller with a perfusion apparatus, such as shown in Fig. 1. Pump and pulse controller 2500 receives pressure sensor data input 2510 from pressure sensor P and tachometer data input 2520. A tachometer may be used to set the phase angle of the active wave. Pump and pulse controller 2500
10 converts this information to motor drive output 2530, which powers pump 2540. Fig. 25A shows various modes of operation that pump and pulse controller 2500 can provide and how pump and pulse controller 2500 eliminates pressure pulse waves from the perfusate flow and how it modulates perfusate flow rate while maintaining a constant pressure pulse rate.

15 A peristaltic pump driven at a constant speed provides a constant pressure wave in the associated tubing. Fig. 25A shows in the first mode of operation the waveforms that result from a constant drive speed applied to a peristaltic pump. The second mode of operation, called active continuous, shows how the pressure pulse wave can be eliminated or canceled out by applying a motor drive wave that is
20 opposite to the pressure wave of the pump. In the third mode of operation, called active waveform amplitude modulating, the pump pressure pulse wave is canceled by the motor drive wave, and a selected wave is added with a new amplitude as compared to the original pressure pulse wave amplitude. In the fourth mode of operation, called active waveform pulse width modulating, the pump pressure pulse
25 wave is canceled by the motor drive wave, and a selected wave is added with a new pulse width as compared to the original pressure pulse wave width. In an alternative mode of operation, the frequency may be modulated by adding a new frequency wave to the canceled waves.

30 A level sensor L2 in communication with the microprocessor 150 (see Fig. 3) ensures that a predetermined level of effluent medical fluid is maintained within the organ chamber 40. As shown in Fig. 2, a temperature sensor T1 disposed in the tubing 91 relays the temperature of the medical fluid pumped out of the organ bath along tubing 91 to the microprocessor 150, which monitors the same. A pressure

sensor P2 disposed along the tubing 91 relays the pressure therein to the microprocessor 150, which shuts down the system if the fluid pressure in the tubing 91 exceeds a predetermined limit, or activates an alarm to notify the operator that the system should be shut down, for example, to clean filters or the like.

5 As the medical fluid is pumped along tubing 91 it preferably passes through a filter unit 95 (e.g., 25 μ , 8 μ , 2 μ , 0.8 μ , 0.2 μ and/or 0.1 μ filters); a CO₂ scrubber/O₂ membrane 100 and an oxygenator 110, for example, a JOSTRA™ oxygenator. The CO₂ scrubber/O₂ membrane 100 is preferably a hydrophobic macroporous membrane with a hydrophilic (e.g., Hypol) coating in an enclosure. A vacuum source (not
10 shown) is utilized to apply a low vacuum on a side opposite the hydrophilic coating by the activation of valve VV₁. A hydrostatic pressure of approximately 100 mm Hg is preferred for aqueous passage through the membrane. The mechanical relief valve (not shown) prevents the pressure differential from attaining this level. Immobilized pegolated carbonic anhydrase may be included in the hydrophilic coating. This allows
15 bicarbonate to be converted to CO₂ and subsequently removed by vacuum venting. However, with organs such as kidneys which have the ability to eliminate bicarbonate, this may be unnecessary except in certain cases.

The oxygenator 110 is preferably a two stage oxygenator which preferably includes a hydrophilically coated low porosity oxygen permeable membrane. A
20 portion of the medical fluid is diverted around the oxygenator along tubing 111 in which is disposed a viability sensor V1, which senses fluid characteristics, such as organ resistance (pressure/flow), pH, pO₂, pCO₂, LDH, T/GST, Tprotein, lactate, glucose, base excess and ionized calcium levels indicative of an organ's viability. The viability sensor V1 is in communication with the microprocessor 150 and allows the
25 organ's viability to be assessed either automatically or manually. One of two gases, preferably 100% oxygen and 95/5% oxygen/carbon dioxide, is placed on the opposite side of the membrane depending on the pH level of the diverted medical fluid. Alternatively, another pump (not shown) may be provided which pumps effluent medical fluid out of the organ chamber 40 and through a viability sensor before
30 returning it to the bath, or the viability sensor can be placed on tubing 81 utilizing pump 80. In embodiments, the fluid characteristics may be analyzed in a separate diagnostic apparatus and/or analyzer as shown in Figs. 28-31.

5 The sensed fluid characteristics, such as organ resistance (pressure/flow), pH, pO₂, pCO₂, LDH, T/GST, Tprotein, lactate, glucose, base excess and ionized calcium levels may be used to analyze and determine an organ's viability. The characteristics may be analyzed individually or multiple characteristics may be analyzed to determine the effect of various factors. The characteristics may be measured by capturing the venous outflow of the organ and comparing its chemistry to the perfusate inflow. The venous outflow may be captured directly and measured or the organ bath may be measured to provide a rough approximation of the fluid characteristics for comparisons over a period of time.

10 In embodiments, an organ viability index is provided taking into account the various measured factors identified above, such as vascular resistance, pH, etc. The index may be organ specific, or may be adaptable to various organs. The index compiles the monitored parameters into a diagnostic summary to be used for making organ therapy decisions and deciding whether to transplant the organ. The index may be automatically generated and provided to the physician. The index is preferably
15 computer generated via a connection to the perfusion apparatus, transporter, cassette and/or organ diagnostic apparatus. The additional information, such as donor specific information, may be entered into a single computer at the site of the perfusion apparatus, transporter, cassette and/or organ diagnostic apparatus or may be entered in
20 a remote computer and linked to the perfusion apparatus, etc. In embodiments, the index may be made available over a computer network such as a local area network or the Internet for quick comparison, remote analysis and data storage.

The organ viability index provides measurements and normal ranges for each characteristic, such as vascular resistance and perfusate chemistry characteristics
25 based on pH, pO₂, pCO₂, LDH, T/GST, Tprotein, lactate, glucose, base excess and ionized calcium levels. For example, at approximately 5° C, normal pH may be from 7.00 and 8.00, preferably from 7.25 and 7.75 and more preferably from 7.50 and 7.60 and base excess may be in the range of from -10 to -40, preferably from -15 to -30, and more preferably from -20 to -25. Measurements that are outside the normal range
30 may be indicated visually, e.g., by an asterisk or other suitable notation, aurally or by machine perceivable signals. The characteristics give the physician insight into the metabolism of the organ, such as stability of the metabolism, consumption of glucose, creation of lactic acid and oxygen consumption.

The index may also provide identifying information, such as age, gender, blood type of the donor and any expanded criteria; organ information, such as organ collection date and time, warm ischemia time, cold ischemia time and vascular resistance; apparatus information, such as flow rate, elapsed time the pump has been operating and pressure; and other identifiers such as UNOS number and physician(s) in charge. The index may additionally provide temperature corrections if desired.

Returning to Fig. 2 and the flow and/or treatment of the medical fluid or perfusate in perfusion apparatus 1, alternative to the pump 90, filter unit 95, the CO₂ scrubber/O₂ membrane 100 and/or the oxygenator 110, a modular combined pump, filtration, oxygenation and/or debubbler apparatus may be employed such as that described in detail in simultaneously filed co-pending U.S. Patent Application No. 09/039,318, which is hereby incorporated by reference. As shown in Figs. 4 - 10, the apparatus 5001 is formed of stackable modules. The apparatus 5001 is capable of pumping a fluid through a system as well as oxygenating, filtering and/or debubbling the fluid. The modules are each formed of a plurality of stackable support members and are easily combinable to form a compact apparatus containing desired components. Filtration, oxygenation and/or degassing membranes are disposed between the support members.

Figures 4-8 show various modules that may be stacked to form a combined pump, filtration, oxygenation and/or debubbler apparatus, such as the combined pump, filtration, oxygenation and debubbler apparatus 5001 shown in Figs. 9-10. As depicted in these figures, the combined pump, filtration, oxygenation and debubbler apparatus 5001 is preferably formed of a plurality of stackable support members groupable to form one or more modules.

Interposed between the plurality of stackable support member are filtration, oxygenation and/or degassing membranes depending on a particular user's needs. The filtration, oxygenation and/or degassing membranes are preferably commercially available macro-reticular hydrophobic polymer membranes hydrophilically grafted in a commercially known way, such as, for example, ethoxylation, to prevent protein deprivation, enhance biocompatibility with, for example, blood and to reduce clotting tendencies. The filtration membrane(s) is preferably hydrophilically grafted all the way through and preferably has a porosity (pore size) within a range of 15 to 35 μ , more preferably 20 to 30 μ , to filter debris in a fluid, preferably without filtering out

cellular or molecular components of the fluid. The degassing membrane(s) and oxygenation membrane(s) are hydrophilically surface treated to maintain a liquid-gas boundary. The degassing membrane(s) and oxygenation membrane(s) preferably have a porosity of 15μ or less, more preferably 10μ or less.

5 The modules may include a first pump module 5010, as shown in exploded view in Fig. 4; a filtration module 5020, as shown in exploded view in Fig. 5; an oxygenation module 5030, as shown in exploded view in Fig. 6; a debubbler module 5040, as shown in exploded view in Fig. 7; and a second pump module 5050, as shown in exploded view in Fig. 8. The pump modules are each connected to a source
10 of pump fluid and are actuated either manually or by the microprocessor. The support members are preferably similarly shaped. For example, the support members may each be plate-shaped; however, other shapes may also be appropriate. As shown in Fig. 10, the support members are preferably removably connected by screws or bolts 5065; however, other fasteners for assembling the apparatus may also be appropriate.

15 The first pump module 5010 preferably includes a first (end) support member 5011, a second support member 5012 with a cut-out center area 5012c, a diaphragm 5013 and a third support member 5014. The support members of this module and each of the other modules are preferably thin and substantially flat (plate-like), and can be formed of any appropriate material with adequate rigidity and preferably also
20 biocompatibility. For example, various resins and metals may be acceptable. A preferred material is an acrylic/polycarbonate resin.

 The first (end) support member 5011 is preferably solid and provides support for the pump module 5010. The first (end) support member 5011 preferably includes a domed-out cavity for receiving pump fluid such as air. Tubing 5011t is provided to
25 allow the pump fluid to enter the pump module 5010. The diaphragm 5013 may be made of any suitable elastic and preferably biocompatible material, and is preferably polyurethane. The third support member 5014 includes a domed-out fluid cavity 5014d and tubing 5014t for receiving fluid, such as, for example, blood or an artificial perfusate, into the cavity 5014d of the pump module 5010. The first pump module, or
30 any of the other modules, may also include a port 5014p for sensors or the like. Preferably hemocompatible anti-backflow valves serve to allow unidirectional flow through the pump module 5010.

The filtration module 5020 preferably includes a filtration membrane 5021m which forms a boundary of cavity 5014d, a first support member 5022 with a cut-out center area 5022c, a degassing membrane 5022m and second and third support members 5023 and 5024. The filtration membrane 5021m is preferably a 25 μ macro-reticular filtration membrane modified to enhance biocompatibility with, for example, blood and to reduce clotting tendencies (like the other supports, filters and membranes in the device). The degassing membrane 5022m is preferably a 0.2 - 3 μ macro-reticular degassing membrane with a reverse flow aqueous pressure differential of at least 100 mmHg for CO₂ removal surface modified to enhance biocompatibility.

The first support 5022 includes tubing 5022t for forwarding fluid into the oxygenation module 30, or another adjacent module, if applicable, after it has passed through the filtration membrane 5021m and along the degassing membrane 5022m. The second support member 5023 of the filtration module 5020 includes a domed-out fluid cavity 5023d and tubing 5023t through which a vacuum may be applied to the cavity 5023d to draw gas out of the fluid through degassing membrane 5022m. The fourth support member 5024 is preferably solid and provides support for the filtration module 5020. The third support member can also include tubing 5024t through which a vacuum may be applied to draw gas out of the fluid through the degassing membrane 5031m of the oxygenation module 5030 as discussed below. The filtration module 5020, or any of the other modules, may also include a port 5023p for sensors or the like.

The oxygenation module 5030 includes a degassing membrane 5031m, a first support member 5032, a filtration membrane 5033m, an oxygenation membrane 5034m, a second support member 5034 with a cut-out center area 5034c, and third and fourth support members 5035, 5036. The degassing membrane 5031m is preferably a 0.2 - 3 μ macro-reticular degassing membrane with a reverse flow aqueous pressure differential of at least 100 mmHg surface modified to enhance biocompatibility.

The first support member 5032 includes a domed-out fluid cavity 5032d. The surface of the domed-out fluid cavity 5032d preferably forms a tortuous path for the fluid, which enhances the oxygenation and degassing of the fluid. The filtration membrane 5033m is preferably a 25 μ macro-reticular filtration membrane modified to enhance biocompatibility. The oxygenation membrane 5034m is preferably a 0.2 - 1 μ

macro-reticular oxygenation membrane with a reverse flow aqueous pressure differential of at least 100 mmHg surface modified to enhance biocompatibility.

5 The second support member 5034 includes tubing 5034t for forwarding fluid out of the oxygenation module 5030 into the debubbler module 5040, or another adjacent module, if applicable. The third support member 5035 includes a domed-out cavity 5035d and tubing 5035t for receiving oxygen from an external source. The fourth support member 5036 is preferably solid and provides support for the oxygenation module 5030.

10 The debubbler module 5040 includes a first support member 5041, a filtration membrane 5042m, a degassing membrane 5043m, a second support member 5043 having a cut-out center area 5043c, and a third support member 5044. The first support member 5041 has a domed-out fluid cavity 5041d.

15 The filtration membrane 5042m is preferably a 25μ macro-reticular filtration membrane modified to enhance biocompatibility. The degassing membrane 5043m is preferably a $0.2 - 3\mu$ macro-reticular degassing membrane with a reverse flow aqueous pressure differential of at least 100 mmHg surface modified to enhance biocompatibility. The second support member 5043 has tubing 5043t for forwarding fluid out of the debubbler module 5040 into the pump module 5050, or another adjacent module, if applicable. The third support member 5044 includes a domed-out cavity 5044d and tubing 5044t through which a vacuum may be applied to draw gas out of the fluid through the degassing membrane 5043m.

20 The second pump module 5050 may correspond to the first pump module 5010. It preferably includes a first support member 5051, a diaphragm 5052, a second support member 5053 with a cut-out center area 5053c, and a third (end) support member 5054. The first support member 5051 includes a domed out fluid cavity 5051d and tubing 5051t for allowing fluid to exit the pump module. The diaphragm 5052 is preferably a polyurethane bladder.

25 The third (end) support piece member 5054 is preferably solid and provides support for the pump module 5050. Support member 5054 preferably includes a domed out cavity (not shown) for receiving pump fluid. Tubing 5054a is provided to allow the pump fluid such as air to enter the pump module 5050. Preferably hemocompatible anti-backflow valves may serve to allow unidirectional flow through the pump module 5050.

In operation, blood and/or medical fluid enters the first pump module 5010 through tube 5014t passes through the filtration membrane 5021m and along the degassing membrane 5022m. A small vacuum is applied through tubing 5023t to draw gas through the degassing membrane 5022m. Next, the blood and/or medical fluid travels into the oxygenation module 5030 via internal tubing 5022t, passing along the degassing membrane 5031m, through the filtration membrane 5033m and along the oxygenation membrane 5034m. Oxygen is received into the domed-out cavity 5035d of the third support member of the oxygenation module 5030 via tubing 5035t and passes through the oxygenation membrane 5034m into the blood and/or medical fluid as the blood and/or medical fluid travels along its surface.

After being oxygenated by the oxygenation module 5030, the blood and/or medical fluid then travels via internal tubing 5034t into the debubbler module 5040. The blood and/or medical fluid passes through the filtration membrane 5042m and along the degassing membrane 5043m. A small vacuum force is applied through tubing 5044t to draw gas out of the blood and/or medical fluid through the degassing membrane 5043m. After passing through the degassing module 5040, the blood and/or medical fluid travels into the second pump module 5050 through tubing 5041t, and exits the second pump module 5050 via tubing 5051t.

After passing through the oxygenator 110, or alternatively through the combined pump, oxygenation, filtration and/or degassing apparatus 5001, the recirculated medical fluid is selectively either directed to the reservoir 15a or 15b not in use along tubing 92a or 92b, respectively, by activating the respective valve LV₂ and LV₅ on the tubing 92a or 92b, or into the organ chamber 40 to supplement the organ bath by activating valve LV₁. Pressure sensors P3 and P4 monitor the pressure of the medical fluid returned to the bag 15a or 15b not in use. A mechanical safety valve MV₂ is provided on tubing 91 to allow for emergency manual cut off of flow therethrough. Also, tubing 96 and manual valve MV₁ are provided to allow the apparatus to be drained after use and to operate under a single pass mode in which perfusate exiting the organ is directed to waste rather than being recirculated (recirculation mode.)

A bicarbonate reservoir 130, syringe pump 131 and tubing 132, and an excretion withdrawal unit 120, in communication with a vacuum (not shown) via

vacuum valve VV_2 , and tubing 121a, 122a are also each provided adjacent to and in communication with the organ chamber 40.

The present invention also provides for perfusion apparatus adapted for organs with complex vasculature structures, such as the liver. Using the liver as an example, Fig. 26 shows perfusion apparatus 2600. Perfusion apparatus 2600 has a single pump 2610, which is preferably a roller pump or peristaltic pump. The tubing splits into two or more directions with, for example, three tubes going toward the portal vein side of the liver (portal tubing 2625) and one tube going toward the hepatic artery side of the liver (hepatic tubing 2626). The portal side of perfusion apparatus 2600 has more tubes because the portal side of the liver uses three to ten times the flow that the hepatic side uses. Fig. 27 shows a perspective view of pump 2610 and the tubing split into portal tubing 2625 and hepatic tubing 2626.

Both the portal side and the hepatic side of perfusion apparatus 2600 preferably have a filter 2630, bubble trap 2640, pressure transducer 2650, temperature transducer 2660, and flow sensor 2670. An additional temperature transducer 2660 may be present in fluid return tubing 2620. The organ may be cooled as discussed above, for example by an ice and water bath 2680 or by a cryogenic fluid. In embodiments using cryogenic fluids, the design should be such that organ freezing is prevented.

Multiple pumps may be used; however, utilizing multiple pumps generally increases the size and cost of the apparatus. Utilizing a single pump 2610 for both vasculature systems provides a variety of modes that can be used to perfuse a liver. After each bubble trap 2640, the tubing splits into two directions. On the hepatic side, hepatic infusion valve 2685 controls the flow to the hepatic side of the liver and hepatic wash valve 2686 controls the flow into the organ bath. On the portal side, portal infusion valve 2695 controls the flow to the portal side of the liver and portal wash valve 2696 controls the flow into the organ bath. Preferably, each pair of infusion valves and wash valves operates in an on/off or either/or manner. In other words, when, for example, the portal side is set to infuse, the portal wash valve 2696 is closed. The following table shows various modes of operation for perfusion apparatus 2600.

MODES OF OPERATION	PORTAL VALVES	HEPATIC VALVES	DOMINANT PRESSURE	NOTES
Portal Only	Infuse	Wash	Portal	No hepatic perfusion
Portal Priority	Infuse	Infuse	Portal	Hepatic slave to portal
Hepatic Only	Wash	Infuse	Hepatic	No portal perfusion
Hepatic Priority	Infuse	Infuse	Hepatic	Portal slave to hepatic
Alternating	Infuse	Switching	Alternating	Wavy portal flow; pulsed hepatic flow

5 The modes of operation identified in the table above show options for infusing a liver. In the first mode, Portal Only, the portal side of the liver is infused. Therefore, the portal valves are set to infuse, which means that portal infusion valve 2695 is open and portal wash valve 2696 is closed. Also, in a Portal Only mode, hepatic infusion valve 2685 is closed and hepatic wash valve 2686 is open. In a Portal
10 Only mode, the portal pressure is dominant, which means the pressure is controlled by the pressure transducer 2650 on the portal side. In this mode, there is no hepatic infusion.

 In a Portal Priority mode, the portal valves and the hepatic valves are set to infuse. The portal pressure is dominant; and therefore, the hepatic side is a slave to
15 the portal side. In an Alternating mode, the portal valves are set to infuse and the hepatic valves switch between an infuse setting and a wash setting. In an Alternating mode, when the hepatic valves are set to infuse, the hepatic side provides the dominant pressure. When the hepatic valves are set to wash, the portal side provides the dominant pressure. This type of alternating pressure control provides the portal
20 side with a wavy flow and provides the hepatic side with a pulsed flow.

 The present invention also provides an organ diagnostic system 2800 shown in Fig. 28. Organ diagnostic system 2800 has a computer 2810 and an analyzer 2820.

Connected to both computer 2810 and analyzer 2820 is an organ evaluation instrument 2830, also shown in Fig. 29. Organ diagnostic system 2800 is preferably provided with suitable displays to show the status of the system and the organ. Organ evaluation instrument 2830 has a perfusate chamber 2840 and an organ chamber 2850. Connecting analyzer 2820 and organ evaluation instrument 2830 is a transfer line 2860. Organ diagnostic system 2800 provides analysis of an organ and produces an organ viability index quickly and in a sterile cassette, preferably transferable from perfusion apparatus 1 and/or transporter 1900. The organ viability index is preferably produced by flow and temperature programmed single-pass perfusion and in-line automatic analysis. The analysis may be performed in a multi-pass system, although a beneficial aspect of the single-pass system is that it can be configured with a limited number of sensors and requires only enough perfusate to perform the analysis. Single-pass perfusion also allows for an organ inflow with a perfusate having a known and predetermined chemistry. This increases the flexibility of types and contents of perfusates that may be delivered, which can be tailored and modified to the particular analysis in process.

Fig. 29 shows a perspective view of organ evaluation instrument 2830. Organ evaluation instrument 2830 has a perfusate chamber 2840 and an organ chamber 2850. Organ chamber 2850 may be insulated and preferably has a lid 2910 that may be removable or may be hinged. Organ chamber 2850 is preferably configured to receive cassette 65, preferably without opening cassette 65 or jeopardizing the sterility of the interior of cassette 65. Cassette 65 and organ chamber 2850 are preferably constructed to fit or mate such that efficient heat transfer is enabled. The geometric elements of cassette 65 and organ chamber 2850 are preferably constructed such that when cassette 65 is placed within organ chamber 2850, the elements are secure for analysis. A port 2920 is also provided to connect transfer line 2860.

Fig. 30 shows a single-pass fluid system of organ diagnostic system 2800. The initial perfusion fluids 3000 are contained in a chamber 3010. Chamber 3010 is preferably temperature controlled by a heating and cooling system. Fluid flow within the system is monitored by flow sensor 3020 and controlled by signaling to pinch valves 3030 and pumps 3040. The fluid system also provides a bubble trap 3050, a pressure transducer 3060 and a temperature transducer 3070. Heat exchanger 3080 provides temperature control and heating and cooling to the fluid within the system

prior to organ perfusion. The organ is perfused in cassette 65. The fluid in the organ bath may be collected, or the venous outflow may be captured, to be analyzed. The fluid is collected and passed via transfer line 2860 to analyzer 2820. Transfer line 2860 may also be provided with a separate heating and cooling unit. After the fluid is
5 analyzed, it may be collected in a waste receptacle 3090.

Fig. 31 shows a logic circuit for organ diagnostic system 2800. The computer provides control parameters and receives results and data from the analyzer. The logic circuit shows inputs from the sensors to the microcontroller and outputs to hardware elements, such as perfusate coolers, perfusate heaters, pinch valves, pumps,
10 transferline heater/cooler and displays.

The method according to the invention preferably utilizes apparatus such as that discussed above to perfuse an organ to sustain, monitor and/or restore the viability of an organ and/or to transport and/or store the organ. Preservation of the viability of an organ is a key factor to a successful organ transplant. Organs for
15 transplant are often deprived of oxygen (known as ischemia) for extended periods of time due to disease or injury to the donor body, during removal of the organ from the donor body and/or during storage and/or transport to a donee body. The perfusion, diagnostic, and/or transporter apparatus of the present invention have the ability to detect the cell chemistry of an organ to be transplanted in order to adjust the perfusate
20 and control the cellular metabolism to repair ischemic damage to the organ and to prevent reperfusion injury. One specific outcome of ischemic injury may be apoptosis or programmed cell death. Specific agents and additives provided to an organ by the perfusion, diagnostic and/or transporter apparatus, under conditions controlled by the particular apparatus, may interrupt, decrease and/or reverse apoptosis.

25 In preferred methods of the present invention, an organ or tissue is treated ex vivo by mechanical, physical, chemical or genetic manipulation and/or modification to treat disease and/or treat damage to and/or enhance the properties of the organ or tissue. An organ or tissue sample may be removed from a first body, modified, treated and/or analyzed outside the first body and either returned to the first body or
30 transplanted to a second body. An advantage of the apparatus is that it enlarges the time that an organ may be available for ex vivo treatment, e.g., for hours (e.g. 2, 4, 6, 8, 10, 12 or more hours) or even days (e.g. 2, 4, 6, 8, 10, 12 or more days) or weeks (e.g. 1, 2, 3, 4, 5, 6, 7, 8 or more weeks). In preferred embodiments, the perfusion,

diagnostic and/or transporter apparatus of the present invention may be used to provide particular solutions or chemicals to an organ or tissue or may be used to perform particular treatments including flushing or washing an organ or tissue with particular solutions or chemicals. Ex vivo treatments may be performed on tissue or an organ to be transplanted or may be performed on tissue or an organ that has been removed from a patient and is to be returned to the patient after the desired procedure is performed. Ex vivo treatments include but are not limited to treatment of tissue or an organ that has endured a period or periods of ischemia and/or apoxia. Ex vivo treatments may involve performing surgical techniques on an organ, such as cutting and suturing an organ, for example to remove necrotic tissue. Any surgical or other treatment technique that may be performed on tissue or an organ in vivo may also be performed on tissue or an organ ex vivo. The benefit of such ex vivo treatment may be seen, for example, in the application of radiation or chemotherapy to treat a tumor present in or on an organ, to prevent other portions of the patient from being subjected to extraneous radiation or chemotherapy during treatment. The perfusion and transporter apparatus of the present invention also provide additional time for a physician to maintain the tissue or organ before, during and/or after performing a particular technique on the tissue or organ.

Particles trapped in an organ's vasculature may prevent the organ from perfusing properly, or may cause the organ to function improperly, before and/or after transplantation. Perfusion, diagnostic and transporter apparatus of the invention provide ex vivo techniques include perfusing, flushing or washing an organ with suitable amounts of a thrombolytic agent, such as streptokinase, to dissolve blood clots that have formed or to prevent the formation of blood clots in an organ and to open the vasculature of the organ. Such techniques are disclosed, for example, in U.S. Provisional Patent Application _____, filed August 25, 2000, Attorney Docket No. 106996, the entire disclosure of which is hereby incorporated by reference.

Another concern with organ transplantation is the degree to which a recipient may be medicated to prevent organ rejection. In organ transplantation, a further ex vivo technique involves modifying the organ to avoid having it activate the immune system of the donee to prevent or reduce organ rejection and to limit or prevent the need to suppress the donee's immune system before, during and/or after organ transplantation so as to increase the tolerance of the donee to the transplanted organ.

Modifications of an organ may, for example, encourage the donee body to recognize the transplanted organ as autologous. The perfusion, diagnostic and/or transporter apparatus of the present invention may deliver substances such as chemical compounds, natural or modified antibodies, immunotoxins or the like, to an organ and may assist the organ to adsorb, absorb or metabolize such substances to increase the likelihood that the organ will not be rejected. These substances may also mask the organ by blocking, killing, depleting and/or preventing the maturation of allostimulatory cells (dendritic cells, passenger leukocytes, antigen presenting cells, etc.) so that the recipient's immune system does not recognize it or otherwise recognizes the organ as autologous. An organ may be treated just prior to transplantation or may be pretreated hours, days or weeks before transplantation. Such techniques are further described in U.S. Provisional Patent Application No. _____, filed August 25, 2000, Attorney Docket No. 100034, the entire disclosure of which is hereby incorporated by reference.

Substances, such as modified or unmodified immunoglobulin, steroids and/or a solution containing polyethylene glycol (PEG) and an antioxidant such as glutathione, may also be provided to an organ or tissue to mask the organ or to treat the onset of intimal hyperplasia during cryopreservation and/or organ or tissue transplantation. These solutions may be provided to an organ or tissue by perfusion, diagnostic and/or transporter apparatus of the invention. Exemplary such solutions and methods are disclosed in U.S. Patent Application No. 09/499,520, the entire disclosure of which is hereby incorporated by reference.

The perfusion, diagnostic and transporter apparatus of the invention may be used in conjunction with the above techniques and methods and/or in conjunction with further techniques and methods, to perform research on an organ or tissue. The various apparatus may enlarge the time that an organ may be available for ex vivo treatment, e.g., for hours (e.g. 2, 4, 6, 8, 10, 12 or more hours) or even days (e.g. 2, 4, 6, 8, 10, 12 or more days) or weeks (e.g. 1, 2, 3, 4, 5, 6, 7, 8 or more weeks). During the period in which the organ is preserved and/or maintained, various drug research and development may be performed on and/or with the organ. Further treatments may be performed for research purposes, such as developing immunomodification parameters. Since the organ or tissue may be maintained and/or analyzed at or near physiologic parameters, an organ may be tested for the effects of various treatments

and/or substances on the organ or tissue ex vivo. The perfusion, diagnostic and/or transporter apparatus may be used to perfuse blood or a synthetic blood substitute through an organ while monitoring the organ and the organ outflow to analyze the condition of the organ and/or to determine the effect on it of the various treatments.

5 Preferred methods according to the present invention focus on three concepts in order to preserve an organ's viability prior to transplant of the organ into a donee body -- treating the cellular mitochondria to maintain and/or restore pre-ischemia energy and enzyme levels, preventing general tissue damage to the organ, and preventing the washing away of or damage to the vascular endothelial lining of the
10 organ.

The mitochondria are the energy source in cells. They need large amounts of oxygen to function. When deprived of oxygen, their capacity to produce energy is reduced or inhibited. Additionally, at temperatures below 20 °C the mitochondria are unable to utilize oxygen to produce energy. By perfusing the organ with an oxygen
15 rich medical fluid at normothermic temperatures, the mitochondria are provided with sufficient amounts of oxygen so that pre-ischemia levels of reserve high energy nucleotide, that is, ATP levels, in the organ reduced by the lack of oxygen are maintained and/or restored along with levels of enzymes that protect the organ's cells from free radical scavengers. Pyruvate rich solutions, such as that disclosed in U.S.
20 Patent No. 5,066,578, are incapable of maintaining and/or restoring an organ's pre-ischemia energy levels and only function in the short term to raise the level of ATP a small amount. That is, organs naturally have significant pyruvate levels. Providing an organ with additional pyruvate will not assist in restoring and/or maintaining the organ's pre-ischemia energy levels if the mitochondria are not provided with
25 sufficient oxygen to produce energy. Thus, the normothermic perfusion fluid may contain pyruvate but may also contain little or no pyruvate. For example, it can contain less than 6 mM of pyruvate, 5 mM, 4 mM, or even no pyruvate. Other known preservation solutions, such as that disclosed in U.S. Patent No. 5,599,659, also fail to contain sufficient oxygen to restore and/or maintain pre-ischemia energy and enzyme
30 levels.

After maintaining and/or restoring the organ's pre-ischemia energy levels by perfusing the organ with an oxygen rich first medical fluid at normothermic or near-normothermic temperatures (the normothermic mode), the organ is perfused with a

second medical fluid at hypothermic temperatures (the hypothermic mode). The hypothermic temperatures slow the organ's metabolism and conserve energy during storage and/or transport of the organ prior to introduction of the organ into a donee body. The medical fluid utilized in the hypothermic mode contains little or no
5 oxygen, which cannot be utilized by mitochondria to produce energy below approximately 20°C. The medical fluid may include antioxidants and other tissue protecting agents, such as, for example, ascorbic acid, glutathione, water soluble vitamin E, catalase, or superoxide dismutase to protect against high free radical formation which occurs at low temperatures due to the reduction in
10 catalase/superoxide dismutase production. Further, various drugs and agents such as hormones, vitamins, nutrients, antibiotics and others may be added to either solution where appropriate. Additionally, vasodilators, such as, for example, peptides, may be added to the medical fluid to maintain flow even in condition of injury.

Prior to any normothermic perfusion with the oxygen rich first medical fluid at
15 normothermic temperatures, the organ may be flushed with a medical solution containing little or no oxygen and preferably containing antioxidants. The flushing is usually performed at hypothermic temperatures but can, if desired and/or as necessary, be performed at normothermic or near-normothermic temperatures. Flushing can be followed by one or more of hypothermic perfusion, normothermic perfusion, and/or
20 static storage, in any necessary and/or desired order. In some cases, normothermic perfusion may not be necessary.

The normothermic perfusion, with or without prior hypothermic flushing, may also be performed on an organ that has already been subjected to hypothermic temperatures under static or perfusion conditions, as well as on normothermic organs.

25 The organ may be perfused at normothermic or near-normothermic temperatures to sustain, monitor and/or restore its viability prior and/or subsequent to being perfused at hypothermic temperatures for storage and then may be transported without or preferably with hypothermic perfusion. Also, the normothermic perfusion may be performed in vivo prior to removal of the organ from the donor body. Further,
30 the organ may be perfused at normothermic temperatures to sustain, monitor and/or restore its viability prior to being perfused at hypothermic temperatures preparatory to storage and/or transport. Then the organ may be transplanted into a donee body while remaining at hypothermic temperatures, or it may first be subjected to normothermic

perfusion to help it recover from the effects of storage and/or transport. In the latter case, it may then be transplanted at normothermic temperatures, or preferably, be hypothermically perfused again for transplantation at hypothermic temperatures. After transplant, the organ may optionally again be perfused at normothermic
5 temperatures in vivo, or allowed to warm up from the circulation of the donee.

By way of Example only, and without being limited thereto, Fig. 16 shows an exemplary diagram of possible processing steps according to the invention. The Figure shows various possible processing steps of multiple organ recovery (MOR) from organ explant from the organ donor through implant in the donee, including
10 possible WIT (warm ischemia time) and hypoxia damage assessment. Several exemplary scenarios are set forth in the following discussion.

For example, in one embodiment of the present invention, the organ can be harvested from the donor under beating heart conditions. Following harvesting, the organ can be flushed, such as with any suitable solution or material including, but not
15 limited to VIASPAN (a preservation solution available from DuPont), other crystalloid solution, dextran, HES (hydroxyethyl starch), solutions described in U.S. Patent Application 09/628,311, filed July 28, 2000, the entire disclosure of which is hereby incorporated by reference, or the like. The organ can then be stored statically, for example, at ice temperatures (for example of from about 1 to about 10°C).

20 In another embodiment, such as where the organ has minimal WIT and minimal vascular occlusion, a different procedure can be used. Here, the organ can again be harvested under beating heart conditions, followed by flushing, preferably at hypothermic temperatures. If necessary to transport the organ, the organ can be stored in a suitable transporter at, for example, ice temperatures. Flow to the organ can be
25 controlled by a set pressure maximum, where preset pressure minimum and pressure maximum values control the pulse wave configuration. If necessary to store the organ for a longer period of time, such as for greater than 24 hours, the organ can be placed in the MOR. In the MOR, a suitable perfusate can be used, such as a crystalloid solution, dextran or the like, and preferably at hypothermic temperatures. Preferably,
30 the hypothermic temperatures are from about 4 to about 10°C, but higher or lower temperatures can be used, as desired and/or necessary. Preferably, the perfusate solution contains specific markers to allow for damage assessment, although damage

assessment can also be made by other known procedures. When desired, the organ can then be returned to the transporter for transport to the implant site.

As a variation of the above procedure, an organ having minimal WIT and minimal vascular occlusion can be harvested under non-beating heart conditions.

5 Here, the organ can be flushed, preferably at hypothermic temperatures and, if necessary, stored for transport in a suitable transporter at, for example, ice temperatures. As above, flow to the organ can be controlled by a set pressure maximum, where preset pressure minimum and pressure maximum values control the pulse wave configuration. The organ can be placed in the MOR, either for extended storage

10 and/or for damage assessment. In the MOR, a suitable perfusate can be used, such as a crystalloid solution, dextran or the like, and preferably at hypothermic temperatures. Preferably, the hypothermic temperatures are from about 4 to about 10°C, but higher or lower temperatures can be used, as desired and/or necessary. Preferably, the perfusate solution contains specific markers to allow for damage assessment, although

15 damage assessment can also be made by other known procedures. Following hypothermic perfusion, a second perfusion can be utilized, preferably at normothermic temperatures. Any suitable perfusion solution can be used for this process, including solutions that contain, as desired, oxygenated media, nutrients, and/or growth factors. Preferably, the normothermic temperatures are from about 12 to about 24°C, but

20 higher or lower temperatures can be used, as desired and/or necessary. The normothermic perfusion can be conducted for any suitable period of time, for example, for from about 1 hour to about 24 hours. Following recovery from the normothermic perfusion, the organ is preferably returned to a hypothermic perfusion using, for example, a suitable solution such as a crystalloid solution, dextran or the

25 like, and preferably at hypothermic temperatures. When desired, the organ can then be returned to the transporter for transport to the implant site.

In embodiments where the organ has high WIT, and/or where there is a high likelihood of or actual; vascular occlusion, variations on the above processes can be used. For example, in the case where the organ is harvested under non-beating heart

30 conditions, the organ can be flushed as described above. In addition, however, free radical scavengers can be added to the flush solution, if desired. As above, the organ can be stored for transport in a suitable transporter at, for example, ice temperatures, where flow to the organ can be controlled by a set pressure maximum, and where

preset pressure minimum and pressure maximum values control the pulse wave configuration. The organ can be placed in the MOR, either for extended storage and/or for damage assessment. In the MOR, a suitable perfusate can be used, such as a crystalloid solution, dextran or the like, and preferably at hypothermic temperatures.

5 Preferably, the hypothermic temperatures are from about 4 to about 10°C, but higher or lower temperatures can be used, as desired and/or necessary. Preferably, the perfusate solution contains specific markers to allow for damage assessment, although damage assessment can also be made by other known procedures. Following

10 hypothermic perfusion, a second perfusion can be utilized, preferably at normothermic temperatures. Any suitable perfusion solution can be used for this process, including solutions that contain, as desired, oxygenated media, nutrients, and/or growth factors. Preferably, the normothermic temperatures are from about 12 to about 24°C, but higher or lower temperatures can be used, as desired and/or necessary. The normothermic perfusion can be conducted for any suitable period of time, for

15 example, for from about 1 hour to about 24 hours. If desired, and particularly in the event that vascular occlusion is determined or assumed to be present, a further perfusion can be conducted at higher normothermic temperatures, for example of from about 24 to about 37°C. This further perfusion can be conducted using a suitable solution that contains a desired material to retard the vascular occlusion. Such

20 materials include, for example, clotbusters such as streptokinase. Following recovery from the normothermic perfusion(s), the organ is preferably returned to a hypothermic perfusion using, for example, a suitable solution such as a crystalloid solution, dextran or the like, and preferably at hypothermic temperatures. When desired, the organ can then be returned to the transporter for transport to the implant site.

25 The organ cassette according to the present invention allows an organ(s) to be easily transported to an organ recipient and/or between organ perfusion, diagnostic and/or portable transporter apparatus, such as, for example, transporter 1900 described above or a conventional cooler or a portable container such as that disclosed in co-

30 pending U.S. Application No. 09/161,919. Because the organ cassette may be provided with openings to allow the insertion of tubing of an organ perfusion, transporter or diagnostic apparatus into the cassette for connection to an organ disposed therein, or may be provided with its own tubing and connection device or devices to allow connection to tubing from an organ perfusion, transporter or diagnostic apparatus and/or

also with its own valve, it provides a protective environment for an organ for storage, analysis and/or transport while facilitating insertion of the organ into and/or connection of an organ to the tubing of an organ perfusion, transporter or diagnostic device.

Further, the organ cassette may also include a handle to facilitate transport of the cassette and may be formed of a transparent material so the organ may be visually monitored.

Optionally, transporter 1900 and/or cassette 65 may include a Global Positioning System (GPS) (not shown) to allow tracking of the location of the organ(s). The apparatus may also include a data logger and/or transmitter (not shown) to allow monitoring of the organ(s) at the location of the apparatus or at another location.

The method of the invention will be discussed below in terms of the operation of the apparatus shown in Fig. 2. However, other apparatus may be used to perform the inventive method.

As previously discussed, the apparatus discussed above can operate in two modes: a normothermic perfusion mode and a hypothermic perfusion mode. The normothermic perfusion mode will be discussed first followed by a discussion of hypothermic perfusion mode. Repetitive description will be omitted as much as possible.

In the normothermic or near-normothermic perfusion mode, an organ is perfused for preferably $\frac{1}{2}$ to 6 hours, more preferably $\frac{1}{2}$ to 4 hours, most preferably $\frac{1}{2}$ to 1 hour, with a medical fluid maintained preferably within a range of approximately 10°C to 38°C, more preferably 12°C to 35°C, most preferably 12°C to 24°C or 18°C to 24°C (for example, room temperature 22-23°C) by the thermoelectric unit 30a disposed in heat exchange communication with the medical fluid reservoir 10.

As discussed above, in this mode, the medical fluid is preferably an oxygenated cross-linked hemoglobin-based bicarbonate solution. Cross-linked hemoglobin-based medical fluids can deliver up to 150 times more oxygen to an organ per perfusate volume than, for example, a simple University of Wisconsin (UW) gluconate type perfusate. This allows normothermic perfusion for one to two hours to partially or totally restore depleted ATP levels. However, the invention is not limited to this preservation solution. Other preservation solutions, such as those disclosed in U.S. Patents Nos. 5,149,321, 5,234,405 and 5,395,314 and co-pending U.S. Patent Applications Nos. 08/484,601 and U.S. Patent Application 09/628,311, filed July 28,

2000, Attorney Docket No. 101311, the entire disclosures of which are hereby incorporated by reference, may also be appropriate.

5 In the normothermic perfusion mode, the medical fluid is fed directly to an organ disposed within the organ chamber 40 from one or the other of bags 15a, 15b via tubing 50a, 50b, 50c or 50d, 50e, 50c, respectively. The organ is perfused at flow rates preferably within a range of approximately 3 to 5 ml/gram/min. Pressure sensor P1 relays the perfusion pressure to the microprocessor 150, which varies the pressure supplied by the pressure source 20 to control the perfusion pressure and/or displays the pressure on the control and display areas 5a for manual adjustment. The pressure is preferably controlled within a range of approximately 10 to 100 mm Hg, preferably 10 50 to 90 mm Hg, by the combination of the pressure source 20 and pressure cuff 15a, 15b in use and the stepping motor/cam valve 65. The compressor and cuffs provide gross pressure control. The stepping motor/cam valve 65 (or other variable valve or pressure regulator), which is also controlled by the operator, or by the microprocessor 15 150 in response to signals from the pressure sensor P1, further reduces and fine tunes the pressure and/or puts a pulse wave on the flow into the organ 60. If the perfusion pressure exceeds a predetermined limit, the stepping motor/cam valve 65 may be activated to shut off fluid flow to the organ 60.

20 The specific pressures, flow rates and length of perfusion time at the particular temperatures will vary depending on the particular organ or organs being perfused. For example, hearts and kidneys are preferably perfused at a pressure of approximately 10 to 100 mm Hg and a flow rate of approximately 3 to 5 ml/gram/min. for up to approximately 2 to 4 hours at normothermic temperatures to maintain and/or restore the viability of the organ by restoring and/or maintaining pre-ischemia energy 25 levels of the organ, and are then preferably perfused at a pressure of approximately 10 to 30 mm Hg and a flow rate of approximately 1 to 2 ml/gram/min. for as long as approximately 72 hours to 7 days at hypothermic temperatures for storage and/or transport. However, these criteria will vary depending on the condition of the particular organ, the donor body and/or the donee body and/or on the size of the 30 particular organ. One of ordinary skill in the art can select appropriate conditions without undue experimentation in view of the guidance set forth herein.

Effluent medical fluid collects in the bottom of the organ chamber 40 and is maintained within the stated temperature range by the second thermoelectric unit 30b.

The temperature sensor T2 relays the organ temperature to the microprocessor 150, which controls the thermoelectric unit 30a to adjust the temperature of the medical fluid and organ bath to maintain the organ 60 at the desired temperature, and/or displays the temperature on the control and display areas 5c for manual adjustment.

5 Collected effluent medical fluid is pumped out by the pump 80 via tubing 81 through the filter unit 82 and then returned to the organ bath. This filters out surgical and/or cellular debris from the effluent medical fluid and then returns filtered medical fluid to act as the bath for the organ 60. Once the level sensor L2 senses that a predetermined level of effluent medical fluid is present in the organ chamber 40
10 (preferably enough to maintain the organ 60 immersed in effluent medical fluid), additional effluent medical fluid is pumped out by the pump 90 through tubing 91. The temperature sensor T1 relays the temperature of the organ bath to the microprocessor 150, which controls the thermoelectric unit 30b to adjust the temperature of the medical fluid to maintain the organ 60 at the desired temperature
15 and/or displays the temperature on the control and display area 5c for manual adjustment and monitoring.

As noted above, the medical fluid can be directed to waste in a single pass mode or recirculated eventually back to the organ and/or bath (recirculation mode.)

20 Along tubing 91, the recirculated medical fluid is first pumped through the filter unit 95. Use of a cross-linked hemoglobin medical fluid allows the use of sub-micron filtration to remove large surgical debris and cellular debris, as well as bacteria. This allows the use of minimal antibiotic levels, aiding in preventing organ damage such as renal damage.

25 Next, the recirculated medical fluid is pumped through the CO₂ scrubber/O₂ membrane 100. The medical fluid passes over the hydrophobic macroporous membrane with a hydrophilic coating (for example, Hypol) and a low vacuum is applied on the opposite side by activating valve VV₁ which removes CO₂ from the recirculated medical fluid.

30 Subsequently, a portion of the medical fluid then enters the oxygenator 110 (for example, a JOSTRA™ oxygenator) and a portion is diverted therearound passing via tubing 111 through the pH, pO₂, pCO₂, LDH, T/GST and Tprotein sensor V1. At this point two gases, preferably 100% oxygen and 95/5% oxygen/carbon dioxide, are respectively placed on the opposite sides of the membrane depending on the pH level

of the diverted medical fluid. The gases are applied at a pressure of up to 200 mm Hg, preferably 50 to 100 mm Hg, preferably through a micrometer gas valve GV₃. The cross-linked hemoglobin-based bicarbonate medical fluid may be formulated to require a pCO₂ of approximately 40 mm Hg to be at the mid point (7.35) of a preferred
5 pH range of 7.25-7.45.

If the medical fluid exiting the oxygenator is within the preferred pH range (e.g., 7.25-7.45), 100% oxygen is delivered to the gas exchange chamber, and valve LV₁ is then not opened, allowing the perfusate to return to the reservoir 10 into the bag 15a or 15b not in use. If the returning perfusate pH is outside the range on the
10 acidic side (e.g., less than 7.25), 100% oxygen is delivered to the gas exchange chamber and valve LV₁ is then opened allowing the perfusate to return to the organ chamber 40. Actuation of syringe pump 131 pumps, for example, one cc of a bicarbonate solution from the bicarbonate reservoir 130, via tubing 132 into the organ bath. Medical fluids with high hemoglobin content provide significant buffering
15 capacity. The addition of bicarbonate aids in buffering capacity and providing a reversible pH control mechanism.

If the returning perfusate pH is outside the range on the basic side (e.g., greater than 7.25), 95/5% oxygen/carbon dioxide is delivered to the gas exchange chamber and valve LV₁ is not actuated, allowing the perfusate to return to the bag 15a or 15b
20 not in use. The bag 15a or 15b not in use is allowed to degas (e.g., any excess oxygen) through valve GV₄. When the bag 15a or 15b in use has approximately 250ml or less of medical fluid remaining therein, its respective cuff 16a, 16b is allowed to vent via its respective gas valve GV₁, GV₂. Then, the respective cuff 16a, 16b of the bag 15a or 15b previously not in use is supplied with gas from the
25 compressed gas source 20 to deliver medical fluid to the organ to continue perfusion of the organ.

In the hypothermic mode, an organ is perfused with a cooled medical fluid, preferably at a temperature within a range of approximately 1°C to 15°C, more preferably 4 °C to 10 °C, most preferably around 10 °C. The medical fluid is
30 preferably a crystalloid perfusate without oxygenation and preferably supplemented with antioxidants and other tissue protecting agents, such as, for example, ascorbic acid, glutathione, water soluble vitamin E, catalase, or superoxide dismutase.

Instead of feeding the medical fluid directly to the organ, the medical fluid may be fed from the reservoir tank 17 via tubing 51 into an intermediary tank 70 preferably having a pressure head of approximately 5 to 40 mm Hg, more preferably 10 to 30 mm Hg, most preferably around 20 mm Hg. Medical fluid is then fed by gravity or, preferably, pressure, from the intermediary tank 70 to the organ 60 along tubing 50c by activating a valve LV₆. The level sensor 71 in the intermediary tank 70 is used to control the feed from reservoir tank 17 to maintain the desired pressure head. Because the medical fluid is fed to the organ by gravity or, preferably, pressure, in the hypothermic mode, there is less perfusion pressure induced damage to the delicate microvasculature of the organ. In fact, the pressure at which the organ is perfused is limited by the pressure head to at most 40 mm Hg.

The stepping motor/cam valve 205 (or other variable valve or pressure regulator) may be arranged on the tubing 50c to provide pulsatile delivery of the medical fluid to the organ 60, to decrease the pressure of the medical fluid fed into the organ 60 for control purposes, or to stop flow of medical fluid into the organ 60, as described above.

Further, in the hypothermic mode, because the organ 60 has less of a demand for nutrients, the medical fluid may be provided to the organ 60 intermittently (e.g., every two hours at a flow rate of up to approximately 100 ml/min.), or at a slow continuous flow rate (e.g., up to approximately 100 ml/min.) over a long period of time. Intermittent perfusion can be implemented in the single pass mode or recirculation mode. The pump 80, filter unit 82 and tube 81 may be used to filter the organ bath along with use of the pH, pO₂, pCO₂, LDH, T/GST and Tprotein sensor; however, because the organ is unable to utilize oxygen at hypothermic temperatures, the oxygenator is not used. If desired and/or necessary, adequate oxygen can be obtained from filtered room air or other suitable source.

Both the perfusate flow and the temperature regulation can be automatically controlled. Such automatic control allows a rapid and reliable response to perfusion conditions during operation. Automatic flow control can be based on the parameters measured from the system, including the perfusate flow rate, the perfusate pH exiting the organ, the organ inlet pressure or timed sequences such as pre-selected flow rates or switching between perfusate modes. Preferably, the flow control is based on pressure monitoring of the perfusate inflow into the organ. The benefits of automatic

flow control include maintaining proper oxygenation and pH control while operating under continuous flow or controlled intermittent flow. Thermal control of the thermoelectric devices (TED) can regulate the temperature of the organ cassette or container and the perfusate reservoir. The thermal control is based on thermal
5 measurements made for example by thermistor probes in the perfusate solution or inside the organ or by sensors in the TED.

The automatic control is preferably effected by an interactive control program using easily operated menu icons and displays. The parameters may be prestored for selection by a user or programmed by the user during operation of the system. The
10 control program is preferably implemented on a programmed general purpose computer. However, the controller can also be implemented on a special purpose computer, a programmed microprocessor or microcontroller and peripheral integrated circuit elements, an ASIC or other integrated circuit, a digital signal processor, a hardwired electronic or logic circuit such as a discrete element circuit, a programmable logic
15 device such as a PLD, PLA, FPGA or PAL, or the like. In general, any device capable of implementing a finite state machine that is in turn capable of implementing the control process described herein may be used. The control program is preferably implemented using a ROM. However, it may also be implemented using a PROM, an EPROM, an EEPROM, an optical ROM disk, such as a CD-ROM or DVD-ROM, and
20 disk drive or the like. However, if desired, the control program may be employed using static or dynamic RAM. It may also be implemented using a floppy disk and disk drive, a writable optical disk and disk drive, a hard drive, flash memory or the like.

In operation, as seen in Fig. 15, the basic steps of operation to control perfusion of one or more organs include first inputting organ data. The organ data
25 includes at least the type of organ and the mass. Then, the program will prompt the user to select one or more types of perfusion modes. The types of perfusion modes, discussed above, include hypothermic perfusion, normothermic perfusion, and sequential perfusion using both normothermic and hypothermic perfusion. When both normothermic and hypothermic perfusion are employed, the user can select between
30 medical fluids at different temperatures. Of course, the system includes default values based on previously stored values appropriate for the particular organ. The user may also select intermittent perfusion, single pass perfusion, and recirculation perfusion.

Depending on the type of perfusion selected, aerobic or anaerobic medical fluids may be specified.

5 Next, the type of flow control for each selected perfusion mode is set. The flow control selector selects flow control based on at least one of perfusate flow rate, perfusate pH, organ inlet pressure and timed sequences. In the preferred embodiment, the flow control is based on detected pressure at the perfusion inlet to the organ. The flow of the medical fluid is then based on the selected perfusion mode and flow control.

10 During operation the conditions experienced by the system, in particular by the organ and the perfusate, are detected and monitored. The detected operating conditions are compared with prestored operating conditions. A signal can then be generated indicative of organ viability based on the comparison. The various detectors, sensors and monitoring devices are described above, but include at least a pressure sensor, a pH detector, an oxygen sensor and a flow meter.

15 The control system may also include a thermal controller for controlling temperature of at least one of the perfusate and the organ. The thermal controller can control the temperature of the medical fluid reservoirs and the organ container by controlling the TEDs. As noted above, temperature sensors are connected to the controller to facilitate monitoring and control.

20 The control system may be manually adjusted at any time or set to follow default settings. The system includes a logic circuit to prevent the operator from setting parameters that would compromise the organ's viability. As noted above, the system may also be operated in a manual mode for sequential hypothermic and/or normothermic perfusion, as well as in the computer controlled mode for sequential
25 hypothermic and/or normothermic perfusion.

 The above described apparatus and method may be used for child or small organs as well as for large or adult organs with modification as needed of the cassettes and or of the pressures and flow rates accordingly. As previously discussed, the organ cassette(s) can be configured to the shapes and sizes of specific organs or organ sizes.
30 The apparatus and method can also be used to provide an artificial blood supply to, such, for example, artificial placentas cell cultures, for growing/cloning organ(s).

 While the invention has been described in conjunction with specific embodiments thereof, it is evident that many alternatives, modifications and variations

may be apparent to those skilled in the art. Accordingly, the preferred embodiments of the invention as set forth herein are intended to be illustrative, not limiting. Various changes may be made without departing from the spirit and scope of the invention.

1. Apparatus for holding an organ for at least one of perfusion, storage, diagnosis and transport of the organ, comprising:
 - a portable housing;
 - an organ supporting surface configured to support an organ within said housing, wherein the portable housing is configured to be received by at least one of an organ perfusion device, an organ transporter and an organ diagnostic device, and includes openings configured to allow tubing to pass therethrough and be connected to the organ, and wherein a bottom portion of the housing is liquid-tight.
2. The apparatus of claim 1, further comprising a valve supported on the housing and configured to control the pressure of medical fluid passed through tubing operably connected to said valve.
3. The apparatus of claim 2, wherein the valve is a variable valve.
4. The apparatus of claim 2, wherein the valve is selected from the group consisting of a stepping motor activated cam valve, a rotary screw valve and a helical screw valve.
5. The apparatus of claim 1, wherein said openings are closed with seals or plugs.
6. The apparatus of claim 1, further comprising a handle disposed on an outer surface of the portable housing.
7. The apparatus of claim 1, further comprising supports configured to support the apparatus when inserted into at least one of an organ perfusion device, an organ transporter and an organ diagnostic device.
8. The apparatus of claim 1, further comprising a first lid.
9. The apparatus of claim 8, wherein said first lid is removable.
10. The apparatus of claim 8, wherein said first lid is attached to said portable housing by a hinge.
11. The apparatus of claim 8, further comprising a second lid interior to said first lid.
12. The apparatus of claim 11, wherein the bottom portion of the housing is configured to collect medical fluid that has passed through a perfused organ to form an organ bath, said apparatus further comprising a channel located in a top portion of the portable housing between said first lid and said second lid in which fluid overflow from the organ bath may be collected and detected.

13. The apparatus of claim 11, further comprising a port in said first lid, in said second lid or in both said first lid and said second lid or in the housing, for obtaining fluid and tissue samples from the organ.

14. The apparatus of claim 11, wherein said first lid and said second lid are transparent.

15. The apparatus of claim 1, further comprising:
tubing connectable to the organ to allow perfusion of the organ; and
at least one connection device configured to allow connection of the tubing to tubing of at least one of an organ perfusion device, an organ transporter and an organ diagnostic device.

16. The apparatus of claim 15, wherein said portable housing is movable to and from said organ perfusion device, organ transporter and organ diagnostic device by connecting and disconnecting said at least one connection device from tubing of said organ perfusion device, organ transporter and organ diagnostic device without opening said portable housing.

17. The apparatus of claim 1, wherein the bottom portion of the housing is configured to collect medical fluid that has passed through a perfused organ to form an organ bath, said apparatus further comprising a stopcock or removable plug contained in said portable housing for draining medical fluid from the organ bath.

18. The apparatus of claim 15, wherein the bottom portion of the housing is configured to collect medical fluid that has passed through a perfused organ to form an organ bath, said apparatus further comprising additional tubing for removing medical fluid from the organ bath.

19. The apparatus of claim 18, wherein said additional tubing has a filter attached thereto to prevent debris of 10 microns in diameter from passing through the additional tubing.

20. The apparatus of claim 1, wherein said organ supporting surface is made of a mesh or porous material.

21. The apparatus of claim 1, wherein said organ supporting surface is removable from said portable housing.

22. The apparatus of claim 1, wherein said organ supporting surface is at least partially perforated to prevent organ debris of 15 microns in diameter from flowing therethrough.

23. The apparatus of claim 1, wherein said organ supporting surface is configured to channel outflow of the organ to allow sampling of the outflow.

24. The apparatus of claim 1, wherein the bottom portion of the housing is configured to collect medical fluid that has passed through a perfused organ to form an organ bath and wherein said organ supporting surface is configured to be raised and lowered within the portable housing and within the organ bath.

25. The apparatus of claim 1, wherein said organ supporting surface or said housing further comprise a tube that is attachable to perfused vasculature of the organ.

26. The apparatus of claim 25, wherein said tube comprises a clamp to secure said tube around the perfused vasculature.

27. The apparatus of claim 25, wherein said tube comprises additional branching sections for attachment to accessory vasculatures.

28. The apparatus of claim 26, wherein said clamp comprises a mechanism that provides control of the pressure that the clamp exerts on the perfused vasculature to avoid damage to the vasculature and to provide leak-tight perfusion of the organ.

29. The apparatus of claim 25, wherein said tube comprises a vent to remove air from the tube.

30. The apparatus of claim 25, wherein said organ supporting surface or said housing comprises detents, tracks or grooves that interact with a protruding region of said tube to allow said cannula to be secured at various positions on the detents, tracks or grooves of the organ supporting surface or the housing.

31. The apparatus of claim 25, wherein said organ supporting surface further comprises straps or belts to secure the organ to the organ supporting surface.

32. The apparatus of claim 1, wherein said portable housing associated with an imaging device to record the status or progress of the organ and/or organ perfusion.

33. The apparatus of claim 1, wherein said apparatus includes at least one of a bar code, magnetic tag, radio frequency tag, transmitter or global positioning system to monitor at least one of the location and identity of the apparatus.

34. The apparatus of claim 1, wherein the portable housing is configured to be received by at least two of an organ perfusion device, an organ transporter and an organ diagnostic device.

35. The apparatus of claim 1, wherein the portable housing is configured to be received by an organ perfusion device, an organ transporter and an organ diagnostic device.

36. The apparatus of claim 1, wherein the portable housing further comprises a closeable air vent.

37. A saleable kit, comprising:

a portable housing;

an organ supporting surface configured to support an organ while allowing effluent medical fluid to pass therethrough, wherein the portable housing is configured to be received by at least one of an organ perfusion device, an organ transporter and an organ diagnostic device, and includes openings configured to allow tubing to pass therethrough and be connected to the organ, and wherein a bottom portion of the housing is liquid-tight and configured to collect medical fluid that has passed through a perfused organ to form an organ bath;

tubing connectable to the organ to allow perfusion of the organ; and

at least one connection device configured to allow connection of the tubing to at least one of an organ perfusion device, an organ transporter and an organ diagnostic device.

38. The kit of claim 37, wherein the housing further comprises at least one lid.

39. The kit of claim 38, wherein at least one of said portable housing and said at least one lid are transparent.

40. The kit of claim 37, wherein the portable housing is configured to be received by at least two of an organ perfusion device, an organ transporter and an organ diagnostic device.

41. The kit of claim 37, wherein the portable housing is configured to be received by an organ perfusion device, an organ transporter and an organ diagnostic device.

42. The kit of claim 37, wherein the portable housing further comprises a closeable air vent.

43. The kit of claim 37, wherein the kit is sterilized.

44. Apparatus for holding an organ for at least one of perfusion, storage, diagnosis and transport of the organ, comprising:

a portable housing;

an organ supporting surface configured to support an organ within said housing while allowing effluent medical fluid to pass therethrough, wherein the portable housing is configured to be received by at least one of an organ perfusion device, an organ transporter and an organ diagnostic device, and includes openings configured to allow tubing to pass therethrough and be connected to the organ, and wherein a bottom portion of the housing is liquid-tight and configured to collect medical fluid that has passed through a perfused organ to form an organ bath.

45. The apparatus of claim 44, further comprising a first cover.

46. The apparatus of claim 45, wherein said first cover is removable.

47. The apparatus of claim 45, wherein said first cover is attached to said portable housing by a hinge.

48. The apparatus of claim 45, further comprising a second cover interior to said first lid.

49. The apparatus of claim 48, further comprising a channel located in a top portion of the portable housing between said first cover and said second cover in which fluid overflow from the organ bath may be collected and detected.

50. The apparatus of claim 48, further comprising a port in said first cover, in said second cover or in both said first cover and said second cover, for obtaining fluid and tissue samples from the organ.

51. The apparatus of claim 48, wherein said first cover and said second cover are transparent.

52. The apparatus of claim 44, wherein said organ supporting surface is at least partially perforated to prevent organ debris of at least 15 microns in diameter from flowing therethrough.

53. The apparatus of claim 44, wherein said organ supporting surface is configured to channel venous outflow of the organ to allow sampling of the venous outflow.

54. The apparatus of claim 44, wherein said organ supporting surface is configured to be raised and lowered within the portable housing and within the organ bath.

55. The apparatus of claim 44, wherein said organ supporting surface or said housing further comprise a cannula that is attachable to a perfused artery of the organ.

56. The apparatus of claim 55, wherein said cannula comprises a cannula clamp to secure said cannula around the perfused artery.

57. The apparatus of claim 55, wherein said cannula comprises additional branching sections for attachment to accessory arteries.

58. The apparatus of claim 55, wherein said cannula clamp comprises a tightening mechanism that provides control of the pressure that the cannula clamp exerts on the perfused artery to avoid damage to the artery and to provide leak-tight perfusion of the organ.

59. The apparatus of claim 56, wherein said cannula comprises a vent to remove air from the cannula.

60. The apparatus of claim 55, wherein said organ supporting surface or said housing comprises detents, tracks or grooves that interact with a protruding region of said cannula to allow said cannula to be secured at various positions on the detents, tracks or grooves of the organ supporting surface or the housing.

61. The apparatus of claim 55, wherein said organ supporting surface further comprises straps or belts to secure the organ to the organ supporting surface.

62. The apparatus of claim 14, wherein said portable housing associated with a video camera or still camera to record the status or progress of the organ and/or organ perfusion.

63. The apparatus of claim 14, wherein said apparatus includes at least one of a bar code, magnetic tag, radio frequency tag, transmitter or global positioning system to monitor the location and identity of the apparatus.

64. The apparatus of claim 44, wherein the portable housing is configured to be received by at least two of an organ perfusion device, an organ transporter and an organ diagnostic device.

65. The apparatus of claim 44, wherein the portable housing is configured to be received by an organ perfusion device, an organ transporter and an organ diagnostic device.

66. The apparatus of claim 44, wherein the portable housing further comprises a closeable air vent.

67. The apparatus of claim 44, further comprising:

tubing connectable to the organ to allow perfusion of the organ; and
at least one connection device configured to allow connection of the tubing to tubing of at least one of an organ perfusion device, an organ transporter and an organ diagnostic device.

68. The apparatus of claim 67, wherein said portable housing is movable to and from said organ perfusion device, organ transporter and organ diagnostic device by connecting and disconnecting said at least one connection device from tubing of said organ perfusion device, organ transporter and organ diagnostic device without opening said portable housing.

69. The apparatus of claim 67, further comprising a stopcock or removable plug contained in said portable housing for draining medical fluid from the organ bath.

70. The apparatus of claim 67, further comprising additional tubing for removing medical fluid from the organ bath.

71. The apparatus of claim 70, wherein said additional tubing has a filter attached thereto to prevent organ debris of at least 10 to 15 microns in diameter from entering the additional tubing.

72. The apparatus of claim 44, wherein said organ supporting surface is made of a mesh or porous material.

73. The apparatus of claim 44, wherein said organ supporting surface is removable from said portable housing.

74. The apparatus of claim 1, wherein the organ supporting surface is substantially in the shape of a chair.

75. The apparatus of claim 1, wherein the organ supporting surface is shaped similar to at least one of a kidney, heart and liver.

76. The apparatus of claim 75, wherein the organ supporting surface is adjustable.

77. The apparatus of claim 27, wherein the additional branching are of multiple sizes.

78. The apparatus of claim 25, wherein the tube is adjustably secured to the organ supporting surface.

79. The apparatus of claim 1, wherein the bottom portion of the housing is configured to collect medical fluid that has passed through a perfused organ to form an organ bath, said apparatus further comprising a stopcock or removable plug contained in said portable housing for draining medical fluid from the organ bath.

80. A method of controlling perfusion of at least one organ with medical fluid, comprising one or more of:
- inputting organ data;
 - selecting one or more types of perfusion modes;
 - selecting a type of flow control for each selected perfusion mode;
 - controlling flow of the medical fluid based on the selected perfusion mode and flow control;
 - detecting operating conditions experienced by the medical fluid and organ during perfusion;
 - comparing detected operating conditions with prestored operating conditions and generating a signal indicative of organ viability based on the comparison; and
 - generating a message relating to organ viability based on the signal generated by the comparator and/or making automatic adjustments to regulate viability.
81. The method of claim 80, wherein selecting a type of flow control includes selecting between aerobic and anaerobic perfusion for each selected perfusion mode.
82. The method of claim 80, wherein selecting one or more types of perfusion modes includes selecting at least one of hypothermic perfusion, normothermic perfusion, and sequential normothermic and hypothermic perfusion.
83. The method of claim 80, wherein selecting one or more types of perfusion modes includes selecting a plurality of medical fluids at different temperatures.
84. The method of claim 80, wherein selecting one or more types of perfusion modes includes selecting at least one of intermittent perfusion, single pass perfusion, and recirculation perfusion.
85. The method of claim 80, wherein selecting a type of flow control includes selecting flow control based on at least one of perfusate flow rate, perfusate pH, organ inlet pressure and timed sequences.
86. The method of claim 80, wherein detecting operating conditions includes detecting pressure, pH, and oxygen levels.
87. The method of claim 80, further comprising controlling temperature of at least one of the perfusate and the organ with a thermal controller.

88. The method of claim 87, wherein controlling the temperature includes regulating temperature of at least one of the organ container and a perfusate reservoir.

89. The method of claim 87, further sensing a temperature of at least one of an organ, an organ container, and a perfusate reservoir and outputting temperature readings to the thermal controller.

90. The method of claim 80, further comprising setting default settings based on organ type for use in the steps of selecting perfusion mode and flow control.

91. The method of claim 80, including controlling perfusion to a plurality of organs.

92. The method of claim 80, wherein inputting organ data includes inputting data relating to organ type and organ mass.

93. A recording medium that stores a control program for use by perfusion system that perfuses at least one organ with a medical fluid, the control program including instructions for one or more of:

- inputting organ data;

- selecting one or more types of perfusion modes;

- selecting a type of flow control for each selected perfusion mode; and

- controlling flow of the medical fluid based on the selected perfusion mode and

- flow control;

- detecting operating conditions experienced by the medical fluid and organ during perfusion;

- comparing detected operating conditions with prestored operating conditions and generating a signal indicative of organ viability based on the comparison; and

- generating a message relating to organ viability based on the signal generated by the comparator and/or making automatic adjustments to regulate viability.

94. The recording medium of claim 93, wherein selecting a type of flow control includes selecting between aerobic and anaerobic perfusion for each selected perfusion mode.

95. The recording medium of claim 93, wherein selecting one or more types of perfusion modes includes selecting at least one of hypothermic perfusion, normothermic perfusion, and sequential normothermic and hypothermic perfusion.

96. The recording medium of claim 93, wherein selecting one or more types of perfusion modes includes selecting a plurality of medical fluids at different temperatures.

97. The recording medium of claim 93, wherein selecting one or more types of perfusion modes includes selecting at least one of intermittent perfusion, single pass perfusion, and recirculation perfusion.

98. The recording medium of claim 93, wherein selecting a type of flow control includes selecting flow control based on at least one of perfusate flow rate, perfusate pH, organ inlet pressure and timed sequences.

99. The recording medium of claim 93, wherein detecting operating conditions includes detecting pressure, pH, and oxygen levels.

100. The recording medium of claim 93, further comprising controlling temperature of at least one of the perfusate and the organ with a thermal controller.

101. The recording medium of claim 100, wherein controlling the temperature includes regulating temperature of at least one of the organ container and a perfusate reservoir.

102. The recording medium of claim 100, further sensing a temperature of at least one of an organ, an organ container, and a perfusate reservoir and outputting temperature readings to the thermal controller.

103. The recording medium of claim 93, further comprising setting default settings based on organ type for use in the steps of selecting perfusion mode and flow control.

104. The recording medium of claim 93, including controlling perfusion to a plurality of organs.

105. The recording medium of claim 93, wherein inputting organ data includes inputting data relating to organ type and organ mass.

106. A method of at least one of maintaining and restoring the viability of at least one organ subjected to a period of ischemia or hypoxia, comprising:

at least one of perfusing and flushing said at least one organ with a first medical fluid at a first hypothermic temperature to reduce or stop catabolic changes.

107. The method of claim 106, wherein said organ prior to said perfusing step is subjected to said period of ischemia or hypoxia without prior hypothermia.

108. The method of claim 106, wherein said perfusing or flushing step reduces or stops catabolic changes selected from the group consisting of free radical activity, apoptic enzymatic degradation and vascular permeability.

109. The method of claim 106, comprising:

flushing said at least one organ with a first medical fluid; and
perfusing said at least one organ with a first medical fluid.

110. The method of claim 109, wherein said flushing is performed prior to said perfusing.

111. The method of claim 109, wherein said flushing is performed subsequent to said perfusing.

112. The method of claim 106, wherein said first medical fluid comprises at least one member selected from the group consisting of antioxidants, anti-apoptic agents, and agents that decrease vascular permeability.

113. The method of claim 106, wherein said organ is continuously perfused with said first medical fluid to ATP recovery over a period of time at said first hypothermic temperature while minimizing catabolic processes initiated by ischemia or hypoxia.

114. The method of claim 106, wherein the first medical fluid is formulated to avoid vascular endothelial damage of the organ.

115. The method of claim 106, wherein the first medical fluid comprises at least one marker for viability measurement.

116. The method of claim 106, wherein the first medical fluid comprises an antioxidant that provides effective buffering activity.

117. The method of claim 106, wherein the first temperature is 2-10°C.

118. The method of claim 106, wherein the organ is perfused at least intermittently at the first temperature within the range of about 5 to about 60 mmHg.

119. The method of claim 106, wherein the organ is perfused continuously at the first temperature within the range of about 5 to about 60 mmHg.

120. The method of claim 106, wherein the organ is perfused at the first temperature using a perfusate pressure source that is incapable of providing pressure greater than 60 mmHg.

121. The method of claim 106, further comprising monitoring the viability of the organ during said perfusing step.

122. The method of claim 121, wherein the viability of the organ is monitored by a sensor that senses fluid characteristics indicative of organ viability and at least one of displays sensed data and relays sensed data to a microprocessor for assessment.

123. The method of claim 121, wherein vascular capillary bed conditions are monitored by a sensor that senses fluid characteristics indicative of vascular capillary bed conditions and at least one of displays sensed data and relays sensed data to a microprocessor for assessment.

124. The method of claim 106, comprising perfusing more than one organ.

125. The method of claim 124, wherein each organ is perfused at the first temperature with the first medical fluid utilizing a pneumatically pressurized medical fluid reservoir controlled in response to a pressure sensor disposed in tubing inserted into each organ.

126. The method of claim 125, wherein each organ is perfused utilizing an individual pneumatically pressurized medical fluid reservoir controlled in response to a pressure sensor disposed in tubing inserted into each organ.

127. The method of claim 106, further comprising collecting medical fluid that has passed through the organ in a separate organ bath for each organ, removing medical fluid from each organ bath, filtering the medical fluid and returning the medical fluid to each organ bath.

128. The method of claim 106, further comprising collecting medical fluid that has passed through the organ from each organ bath and sensing characteristics of the collected medical fluid indicative of organ viability to allow a determination of whether the viability of the organ has been at least one of sustained and restored.

129. The method of claim 106, further comprising collecting medical fluid that has passed through the organ in each organ bath, filtering, degassing and oxygenating the medical fluid and then either returning the medical fluid to each organ bath or to a medical fluid reservoir based on a sensed pH level of the medical fluid.

130. The method of claim 106, wherein the method further comprises switching the perfusion of the organ to a second medical fluid at a second temperature.

131. The method of claim 130, wherein the second medical fluid comprises an oxygen carrier, a free radical scavenger, a pituitary growth factor extract and cell culture media.

132. The method of claim 130, wherein the second medical fluid comprises at least one viability marker.

133. The method of claim 106, wherein the method further comprises perfusing the organ with a second medical fluid at a second temperature at least one of intermittently and continuously to perfuse the organ.

134. The method of claim 133, wherein the second fluid contains an oxygen carrier.

135. The method of claim 134, wherein the second fluid is a simple crystalloid solution carrying dissolved oxygen.

136. The method of claim 135, wherein the second fluid contains at least one of antioxidants and free radical scavengers.

137. The method of claim 133, wherein the second temperature is between about 10 and about 24°C.

138. The method of claim 133, further comprising monitoring the viability of the organ during perfusion at the second temperature.

139. The method of claim 138, wherein the viability of each organ is monitored by a sensor that senses fluid characteristics indicative of at least one of organ viability and vascular capillary bed conditions, and at least one of displays sensed data and relays sensed data to a microprocessor for assessment.

140. The method of claim 133, wherein the organ is perfused at the second temperature at a pressure within a range of approximately 40 to 100 mm Hg.

141. The method of claim 133, wherein the organ is perfused at the second temperature utilizing a pressurized medical fluid reservoir configured to provide pressure no greater than 100 mm Hg.

142. The method of claim 133, wherein the organ is perfused with the second medical fluid at the second temperature utilizing a pneumatic pressure head medical fluid reservoir.

143. The method of claim 142, further comprising utilizing pneumatic control or a stepping motor-activated cam valve provided for each organ and controlled in response to the

pressure sensor disposed in tubing inserted into each organ to at least one of reduce perfusion pressure and put a pulse wave on the medical fluid.

144. The method of claim 106, wherein the method comprises perfusing the organ with the first medical fluid and subsequently at least one of storing and transporting the organ.

145. The method of claim 144, further comprising transplanting the organ into a mammal while the organ remains at the first temperature.

146. The method of claim 106, further comprising at least one of storing and transporting the organ in an organ cassette after perfusion of the organ, the organ cassette including a portable housing and an organ supporting surface configured to support an organ while allowing effluent medical fluid to pass therethrough, the portable housing including openings configured to allow tubing to pass therethrough and be connected to the organ.

147. The method of claim 106, further comprising at least one of storing and transporting the organ in an organ cassette prior to perfusion of the organ with the first medical fluid at the first temperature, the organ cassette including a portable housing; an organ supporting surface; and tubing connectable to the organ to allow perfusion of the organ.

148. The method of claim 106, wherein the organ is perfused with a medical fluid that contains little or no oxygen.

149. The method of claim 148, wherein the medical fluid that contains little or no oxygen comprises at least one member selected from antioxidants, anti-apoptic agents, and agents that decrease vascular permeability.

150. The method of claim 148, wherein the organ is perfused with the medical fluid that contains little or no oxygen at a temperature of from about 4 to about 10°C.

151. The method of claim 148, wherein the organ is disposed in at least one of a portable container, which is capable of maintaining the organ at a temperature of at most 10°C, and a disposable cassette during perfusion with the medical fluid that contains little or no oxygen.

152. The method of claim 106, further comprising prior to perfusing the at least one organ with the first medical fluid at the first temperature, maintaining the organ at a hypothermic temperature.

153. The method of claim 106, comprising placing the organ in a portable container, which is capable of maintaining the organ at a temperature of at most 10°C, to at least one of store and transport the organ.

154. The method of claim 106, comprising placing the organ in a portable perfusion unit to at least one of store and transport the organ.

155. The method of claim 106, comprising placing the organ in a disposable cassette to at least one of store and transport the organ.

156. The method of claim 106, wherein the organ is disposed in at least one of a portable container, which is capable of maintaining the organ at a temperature of at most 10°C, and a disposable cassette during perfusion of the organ with the first medical fluid at the first temperature.

157. A method of at least one of maintaining and restoring the viability of at least one organ subjected to a period of ischemia or hypoxia, comprising:

perfusing said at least one organ with a first medical fluid at a first temperature to reduce or stop catabolic changes in the organ; and

perfusing the organ with a second medical fluid at a second temperature to at least one of store and transport the organ.

158. The method of claim 157, wherein the first medical fluid is a crystalloid solution and the second fluid contains an oxygen carrier.

159. The method of claim 158, wherein the first medical fluid is a simple crystalloid solution augmented with antioxidants and the second fluid is an oxygenated hemoglobin-based solution.

160. The method of claim 157, wherein the first temperature is 4-10°C and the second temperature is at most 10-24°C.

161. The method of claim 157, further comprising monitoring the viability of the organ during perfusion of the organ with the first medical fluid at the first temperature and during perfusion of the organ with the second medical fluid at the second temperature.

162. A method of perfusing an organ, comprising:
perfusing said organ utilizing at least one medical fluid reservoir in communication with a pressure source and a fluid pathway connected to the reservoir and

connectable to the organ, wherein the reservoir and pathway are configured to perfuse the organ at a perfusion pressure controlled at least in part by varying the pressure provided to the reservoir by the pressure source, wherein the reservoir is a flexible container and the pressure source comprises a cuff disposed around the container.

163. The method of claim 162, wherein the pressure source is incapable of providing a pressure exceeding 65 mm Hg.

164. A method of perfusing an organ, comprising:

perfusing an organ utilizing at least one medical fluid reservoir, a fluid pathway connected to the reservoir and connectable to the organ and a variable valve disposed on the fluid pathway, wherein the perfusion pressure is controlled at least in part by the variable valve.

165. The method of claim 164, wherein the variable valve is selected from the group consisting of a stepper motor-activated cam valve, a rotary screw valve, and a helical screw valve.

166. A method of perfusing an organ, comprising:

perfusing an organ utilizing at least one medical fluid reservoir in communication with a pressure head tank and a fluid pathway connected to the pressure head tank and to the organ, wherein the pressure head tank and pathway are configured to perfuse the organ at a perfusion pressure controlled at least in part by the pressure head.

167. A method of perfusing an organ, comprising:

perfusing an organ with a medical fluid;
collecting medical fluid that has passed at least one of into, through and out of the organ;
passing the collected medical fluid through a sensor that senses fluid characteristics indicative of organ viability; and
determining whether an organ remains viable based on said sensed fluid characteristics.

168. The method of claim 167, wherein the sensed fluid characteristics include pH, pO₂, pCO₂, LDH, T/GST, Tprotein and fluorescent tagged copolymer.

169. The method of claim 167, further comprising recording and/or transmitting to a location different from the location of the organ said sensed fluid characteristics to allow monitoring of the organ's viability.

170. A method of transporting and storing an organ, comprising, in sequence:

- a. perfusing said organ at a mild hypothermic temperature to repair damage from warm ischemia;
- b. perfusing said organ at a hypothermic temperature, such as a temperature less than said mild hypothermic temperature of said step a;
- c. at least one of transporting and storing said organ at a mild hypothermic temperature, such as a temperature greater than said hypothermic temperature of said step b; and
- d. perfusing said organ at a mild hypothermic temperature to repair damage from the hypothermic transport or storage of step c.

171. The method of claim 201, wherein said mild hypothermic perfusing steps a and d are performed with an oxygenated perfusion fluid and said hypothermic perfusing step b is performed with a non-oxygenated perfusion fluid.

172. The method of claim 201, wherein step c comprises transporting said organ, and said method further comprises:

- e. perfusing said organ at a hypothermic temperature after step d.
173. The method of claim 203, further comprising:
- f. storing said organ at a hypothermic temperature after step e.
174. The method of claim 203, further comprising transplanting said organ after step e.
175. The method of claim 201, wherein step c comprises transporting said organ to a storage facility, and said method further comprises:

- e. perfusing said organ at a hypothermic temperature and storing said organ at a hypothermic temperature at said storage facility after step d.

176. The method of claim 206, further comprising:

- f. perfusing said organ at a normothermic temperature to repair damage from the hypothermic storage of step e;
- g. perfusing said organ at a hypothermic temperature; and
- h. transporting said organ to a transplant facility at a hypothermic temperature.

177. The method of claim 207, further comprising transplanting said organ after step h.

178. The method of claim 207, further comprising:

- f. perfusing said organ at a normothermic temperature to repair damage from the hypothermic transport of step h;
- g. perfusing said organ at a hypothermic temperature; and
- h. transplanting said organ.

179. Apparatus for perfusing at least one organ, comprising:

at least one medical fluid reservoir;

a fluid pathway connected to the reservoir and connectable to the organ;

a first heat exchanger in heat exchange communication with the medical fluid reservoir;

and

a controller for controlling the first heat exchanger to allow perfusion of the organ with medical fluid at a first hypothermic temperature and a second hypothermic temperature lower than said first hypothermic temperature.

180. A perfusion solution kit, comprising a saleable package containing at least one first container holding a first perfusion solution for hypothermic perfusion at a first temperature and at least one second container holding a second, different perfusion solution for hypothermic perfusion at a second temperature lower than said first temperature.

181. The kit of claim 180 wherein said first perfusion solution contains at least a crystalloid.

182. The kit of claim 180, wherein said first perfusion solution is crystalloid and said second perfusion solution is oxygen carrier enhanced.

183. The kit of claim 182, wherein said oxygen carrier is selected from the group consisting of a hemoglobin and stabilized red blood cells.

184. The kit of claim 182, wherein said oxygen carrier is a hemoglobin.

185. The kit of claim 180, wherein said second perfusion solution contains at least one anti-oxidant or free radical scavenger.

186. The kit of claim 180, wherein said solution contains no more than 5 mM of dissolved pyruvate salt.

187. The kit of claim 180, wherein said first perfusion solution contains at least one vasodilator.

188. The kit of claim 180, wherein said first container and said second container are configured to be operably connected to a perfusion machine as perfusion fluid reservoirs in fluid communication with perfusate conduits of said perfusion machine.

189. The kit of claim 188, wherein at least one of said first container and said second container is compressible to apply pressure to the perfusion solution therein.

190. The kit of claim 188, wherein at least one of said first container and said second container includes a first opening for passage of a contained perfusion solution out of said container and a second opening passage of a compressed gas into said container.

191. The kit of claim 188, wherein said package is a cassette configured to be operably connected to a perfusion machine for connection of said first container and said second container within said cassette in fluid communication with perfusate conduits of said perfusion machine.

192. The method of claim 80, wherein the medical fluid is blood.

193. A control system for controlling perfusion to at least one organ with a medical fluid to maintain viability of the at least one organ, comprising:

- at least one of

- an input for inputting organ data;

- a perfusion selector for selecting one or more types of perfusion modes;

- a control selector for selecting a type of control for each selected perfusion mode;

- and a controller for controlling flow of the medical fluid based on the selected

- perfusion mode and flow control;

- at least one detector for detecting operating conditions experienced by the medical fluid and organ during perfusion;

- a comparator for comparing detected operating conditions with prestored operating conditions and generating a signal indicative of organ viability based on the comparison; and

- an indicator for generating a message relating to organ viability based on the signal generated by the comparator and/or automatically regulating viability.

194. A portable transporter for holding a portable housing, comprising:

- a base portion configured to facilitate an upright position of the transporter;

- a top portion;

a pump;
a power supply; and
a compartment for holding a portable housing, wherein the
the portable housing is configured to contain at least one organ.

195 The transporter of claim 194, further comprising a tube set.

196. The transporter of claim 194, further comprising a latch to secure the top portion
to the bottom portion.

197. The transporter of claim 194, further comprising at least one latch to secure the
top portion with the base portion.

198. A transporter of claim 194 further comprising at least one of a shoulder strap and
wheels to facilitate transportation.

199. The transporter of claim 194, further comprising a control panel,
wherein the control panel displays characteristics of the transporter.

200. The transporter of claim 199, wherein the characteristics are at least one of
infusion pressure, power on/off, error condition, flow rate, flow resistance, infusion temperature,
bath temperature, pumping time, batter charge, temperature profile, status of the top portion, and
history log or graph.

201. The transporter of claim 194, wherein at least a portion of the top portion is
optically clear.

202. The transporter of claim 194, further comprising a sensor that monitors an open or
closed status of the top portion.

203. The transporter of claim 194, wherein an exterior of the top and bottom portions
has a varying outer thickness.

204. The transporter of claim 194, wherein said transporter includes at least one of a
bar code, magnetic tag, radio frequency tag, transmitter or global positioning system to monitor
at least one of the location and identity of the transporter.

205. The transporter of claim 194, wherein the transporter is configured for wired or
wireless communication during transportation.

206. The transporter of claim 194, wherein the transporter is configured to provide
hypothermic perfusion to at least one organ.

207. The transporter of claim 206, further comprising means for controlling temperature of at least one of the perfusate and the at least one organ with a coolant and a thermal controller.

208. The transporter of claim 207, wherein the means for controlling the temperature includes means for regulating temperature of at least one of the organ container and a perfusate reservoir.

209. The transporter of claim 208, further comprising means for sensing a temperature of at least one of an organ, an organ container, and a perfusate reservoir and outputting temperature readings to the thermal controller.

210. The transporter of claim 209, further comprising default settings based on organ type for use in the steps of selecting perfusion mode and flow control.

211. The transporter of claim 210, including means for controlling perfusion to a plurality of organs.

212. The transporter of claim 207, wherein the temperature is within the range of -25 to 60°C.

213. The transporter of claim 194, wherein a default system of the transporter provides cold storage upon failure of the power supply.

214. The transporter of claim 194, wherein a flow rate of the pump is controlled by a computer or microcontroller.

215. The transporter of claim 214, further comprising a pressure transducer to monitor the pressure of the pump.

216. The transporter of claim 207, further comprising an optically clear region of the transporter for viewing the level of coolant.

217. The transporter of claim 207, further comprising a monitor to automatically monitor and control the level of coolant.

218. The transporter of claim 207, wherein the coolant lasts for a minimum of 6 to 12 hours.

219. The transporter of claim 218 wherein the coolant last for 30 to 50 hours

220. The transporter of claim 219, wherein the coolant can be replaced without stopping the perfusion.

221. The transporter of claim 207, further comprising a watertight compartment to hold the coolant.

222. The transporter of claim 194 wherein the housing can be mated with the transporter without opening the portable housing.

223. The transporter of claim 194, wherein the transporter defaults to cold storage upon failure of the power supply.

224. The transporter of claim 194, wherein the pump is a roller pump.

225. The transporter of claim 194, further comprising a monitor to continuously monitor the organ.

226. The transporter of claim 225, further comprising a display.

227. The transporter of claim 194 wherein the transporter is adapted to connect to a local area network.

228. The transporter of claim 227, further comprising a modem.

229. A method of controlling operation of a transporter, comprising:
using a set of controls provided on the transporter to select an operation of the transporter; and
displaying the operation selected;
wherein the operation of the transporter is at least one of priming, washing, error handling, perfusing and idle.

230. The method of claim 229, wherein the controls are manually manually operated.

331. The method of claim 230, the controls include at least one of a button, a knob, a dial, and wireless receiver.

232. The method according to claim 229, wherein the controls are automatically operated.

233. The method of claim 232, wherein automatic operations are controlled by a monitor within the transporter.

234. The method of claim 229, wherein the operation selected is displayed on a control panel.

235. Apparatus for holding an organ for at least one of perfusion, storage, assessment and transport of the organ, comprising:

a portable housing;

a pump;

a pulse controller; and

an organ supporting surface configured to support an organ within said housing, wherein said pump and pulse controller receive at least one of, flow data, tachometer data and pressure data from a pressure sensor and converts the data into an output to drive the pump.

236. The apparatus of claim 235, wherein the pump and pulse controller reduces pressure pulse waves from the perfusate flow.

237. The apparatus of claim 236, wherein the pump and pulse controller maintains a constant pressure wave in said tubing and/or organ.

238. The apparatus of claim 236, wherein the pump and pulse controller synthesize a prescribed pressure wave to be conveyed into said organ.

239. Apparatus for holding an organ for at least one of perfusion, storage, diagnosis and transport of the organ, comprising:

a portable housing;

a pump; and

an organ supporting surface configured to support an organ within said housing, wherein the pump is connected to at least one tube directed to a first area of the organ and the pump is connected to at least one other tube directed to a second area of the organ.

240. The apparatus of claim 239, wherein the number of tubes directed to the first area of the organ differs from the number of tubes directed to the second area of the organ.

241. The apparatus of claim 239, wherein one side of the portable housing comprises one or more of a filter, bubble trap, pressure transducer, temperature transducer and a flow sensor and wherein another side of the portable housing comprises one or more of a filter, bubble trap, pressure transducer, temperature transducer and a flow sensor.

242. An organ assessment system, comprising:

an organ support and at least one organ parameter sensor;

an organ perfusing apparatus, wherein the system is adapted to assess the organ parameters while maintaining the status of the organ during such assessment.

243. A method of assessing an organ comprising:

holding an organ;

sensing an organ parameter; and

diagnosing the organ during a time the organ is held.

244. An organ assessment system comprising:

a computer;

an analyzer;

an organ evaluation instrument in wired or wireless communication with the computer and the analyzer;

a perfusate chamber; and

an organ chamber configured to receive an organ.

245. The system of claim 244, further comprising a display for providing the status of the system and an organ.

246. The system of claim 244, wherein the organ chamber is insulated.

247. The system of claim 244, wherein the organ chamber further comprises a lid.

248. A method of analyzing the viability of an organ comprising:

detecting organ parameters;

compiling the organ parameters; and

producing an index of viability of the organ based on the compiled organ parameters.

249. A method of improving an organ or a tissue, comprising:

removing the organ or tissue from a body;

enhancing the organ or tissue; and

implanting the enhanced organ or tissue into a body.

250. The method of claim 249, comprising removing the organ from a first body and implanting the organ into a second body.

251. The method of claim 249, comprising removing the organ from a first body and implanting the organ into the same body.

252. The method of claim 250, wherein the enhancing comprises applying radiation or chemotherapy to the organ or tissue.

253. The method of claim 250, wherein the enhancing comprises delivering at least one chemical compound to the organ or tissue.

254. The method of claim 253, wherein delivering the chemical compound includes delivering at least one of modified or unmodified immunoglobulin, steroids, polyethylene glycol and antioxidants.

255. The method of claim 249, wherein the organ or tissue is subjected to said enhancing for multiple weeks.

256. The method of claim 249, wherein the enhancing comprises repairing warm ischemia damage.

257. The method of claim 249, wherein the enhancing comprises repairing pre-removal damage.

258. The method of claim 249, wherein the enhancing comprises surgery.

259. The method of claim 249, wherein the enhancing comprises thrombolytic treatment.

260. The method of claim 249, wherein the enhancing comprises antiapoptotic treatment.

261. A method of determining viability of at least one organ, comprising:
flushing the at least one organ;
storing the at least one organ in at least one transporter at cold temperatures;
assessing viability of the at least one organ; and
transporting viable organs to implant sites.

262. Apparatus for holding an organ for at least one of perfusion, storage, assessment and transport of the organ, comprising:

a portable housing;

an organ supporting surface configured to support an organ within said housing, wherein the portable housing is configured to be received by at least one of an organ perfusion device, an organ transporter and an organ assessment device, and includes openings configured to allow tubing to pass therethrough and be connected to the organ, and wherein a bottom portion of the housing is liquid-tight; and

a first lid and a second lid for the housing.

263. An apparatus according to claim 262, wherein an area between the first and second lid defines an overflow channel.

264. Apparatus for holding an organ for at least one of perfusion, storage, assessment and transport of the organ, comprising:

a portable housing defining an overflow trough;

an organ supporting surface configured to support an organ within said housing, wherein the portable housing is configured to be received by at least one of an organ perfusion device, an organ transporter and an organ assessment device, and includes openings configured to allow tubing to pass therethrough and be connected to the organ, and wherein a bottom portion of the housing is liquid-tight.

265. Apparatus for holding an organ for at least one of perfusion, storage, assessment and transport of the organ, comprising:

a portable housing;

an organ supporting surface configured to support an organ within said housing, wherein the portable housing is configured to be received by at least one of an organ perfusion device, an organ transporter and an organ assessment device, and includes openings configured to allow tubing to pass therethrough and be connected to the organ, and wherein a bottom portion of the housing is liquid-tight; and

a first lid and a second lid, wherein at least one said lid includes a biopsy port.--

266. A method of remotely monitoring an organ, comprising:

remotely monitoring information relating to the organ during transportation and storage of the organ.

267. A method according to claim 266, wherein said monitoring comprises monitoring at least one of the location and viability parameters of the organ.

268. A method according to claim 267, wherein the remote monitoring is performed by a system connected to a computer network.

269. A method according to claim 268, further comprising transmitting said information to a prospective recipient of said organ.

270. A method according to claim 266, wherein said monitoring is continuous during transportation of said organ.

271. A transporter for carrying an organ, comprising an information transmission device.

272. A transporter according to claim 271, wherein the transporter includes a global positioning system operably connected to said transmission device.

273. The transporter according to claim 271, further comprising an organ parameter sensor operably connected to said transmission device.

274. The transporter according to claim 271, wherein the transmission device transmits data from the transporter to a remote location.

275. The transporter according to claim 274, wherein the data is at least one of video and picture image data.

276. An organ transportation device comprising:
a transporter and a portable housing,
wherein the portable housing and transporter fit securely together to provide high efficiency heat transfer.

277. A kit comprising:
a saleable package containing a set of tubes, wherein the set of tubes are configured to connect an organ to an organ perfusion apparatus.

278. A kit according to claim 277, wherein the set of tubes includes tubes for connecting a portable housing with an organ.

279. A kit according to claim 278, wherein the set of tubes further comprises tubes for connecting the portable housing to the organ perfusion apparatus.

280. A kit according to claim 277, further comprising an organ support configured to securely hold the organ while the tubes are connected to the organ.

281. Apparatus for holding an organ for at least one of perfusion, storage, diagnosis and transport of the organ, comprising:

a portable housing;
an organ supporting surface configured to support an organ within said housing, wherein the organ supporting surface is removable.

282. The apparatus of claim 281, wherein the organ supporting surface is in the shape of a chair.

283. Apparatus for holding an organ for at least one of perfusion, storage, global assessment and transport of the organ, comprising:

a portable housing;

a signaling device incorporated with the portable housing to identify the housing.

284. A portable organ transporter, comprising:

a base portion configured to facilitate an upright position of the transporter;

a top portion;

a pump;

a power supply;

a compartment for holding a portable housing for an organ; and

an additional compartment for holding a coolant.

285. The portable transporter according to claim 284, wherein the coolant is ice.

286. The portable transporter according to claim 284, wherein the coolant can be replaced without removing the portable housing from the transporter.

287. A portable organ transporter, comprising:

a base portion configured to facilitate an upright position of the transporter;

a top portion;

a pump for providing fluid flow to an organ;

a power supply;

a compartment for holding a portable housing for an organ; and

a diverter system for diverting said fluid flow from said organ.

288. A portable organ transporter according to claim 287, wherein the diverter system diverts the fluid flow during power failure or during a high pressure condition.

289. A portable organ transporter according to claim 287 further comprising a bubble detector.

290. A portable organ transporter, comprising:

a base portion configured to facilitate an upright position of the transporter;

a top portion;

a pump;

a power supply;

a compartment for holding a portable housing for an organ; and
a tube set connectable to the portable housing.

291. The portable transporter of claim 290, wherein the portable housing and tube set can be removed from the transporter without exposing the organ.

292. A portable organ transporter, comprising:
a base portion configured to facilitate an upright position of the transporter;
a top portion;
a pump;
a power supply, wherein the power supply can be replaced without the transporter losing power.

293. A portable organ transporter, comprising:
a base portion configured to facilitate an upright position of the transporter;
a top portion;
a pump for providing fluid flow to an organ;
a power supply; and
a compartment for holding accessories.

294. The portable organ transporter according to claim 293, wherein the compartment is configured to hold medical charts.

295. Apparatus for holding an organ for at least one of perfusion, storage, assessment and transport of the organ, comprising:

a sensor to detect the presence of a portable housing for an organ in the apparatus.

296. An apparatus of claim 295, wherein said apparatus is an organ transporter.

297. A method of analyzing factors involved in organ transplantation or implantation, comprising:

comparing outcomes of organs transplants in recipients, and comparing organ history during transport and/or storage.

298. All methods, apparatus and products, and sub-steps and sub-portions thereof, individually and in combination, as shown and/or described herein.

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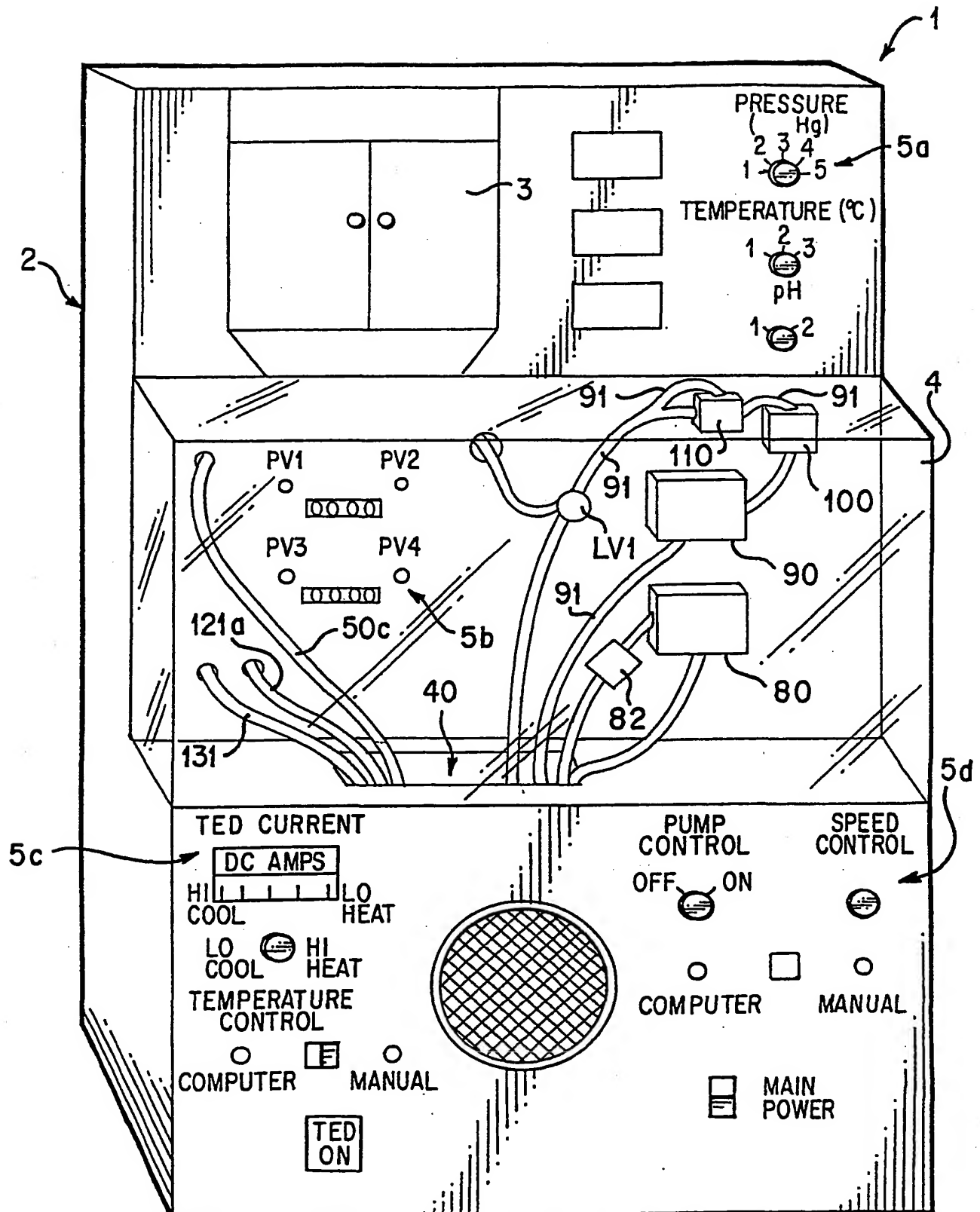


FIG. 1

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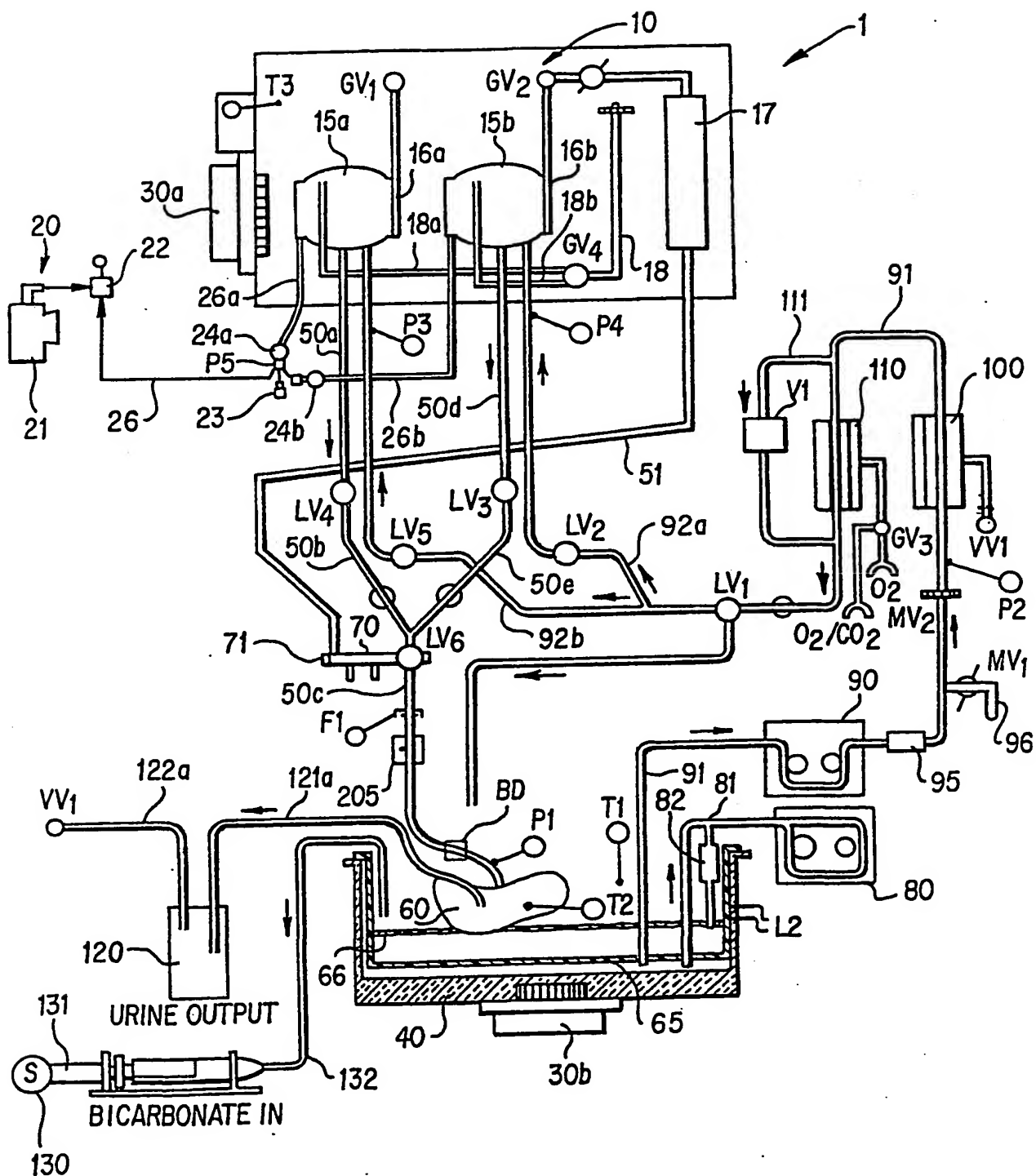


FIG. 2

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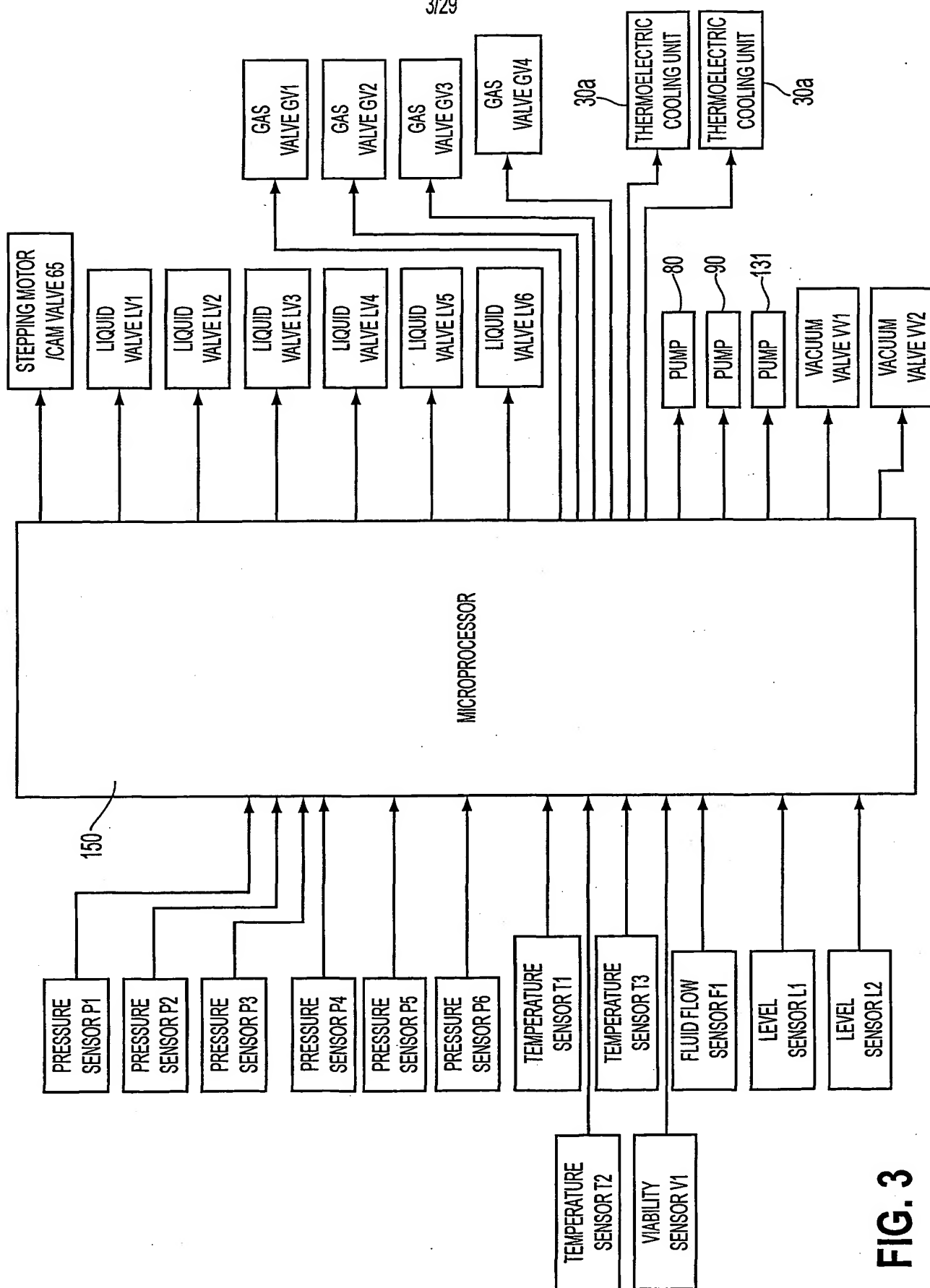


FIG. 3

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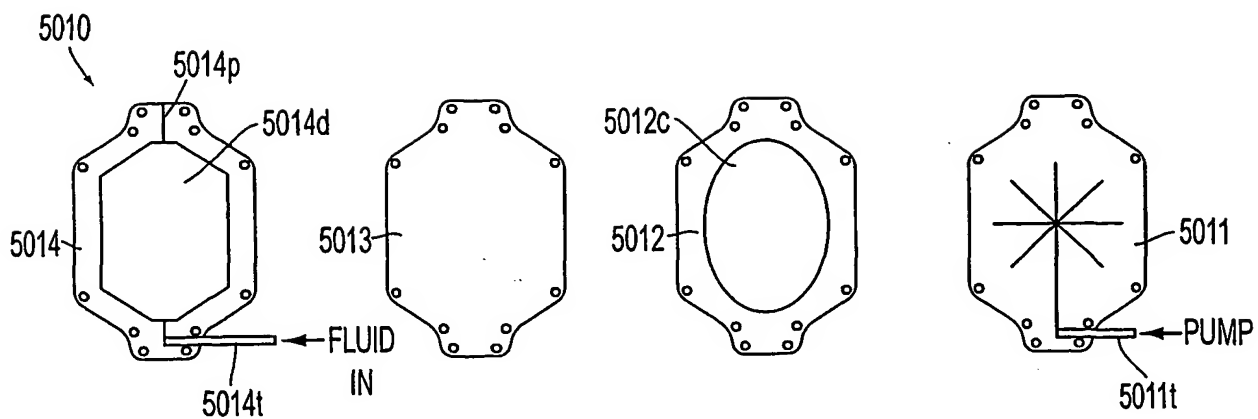


FIG. 4

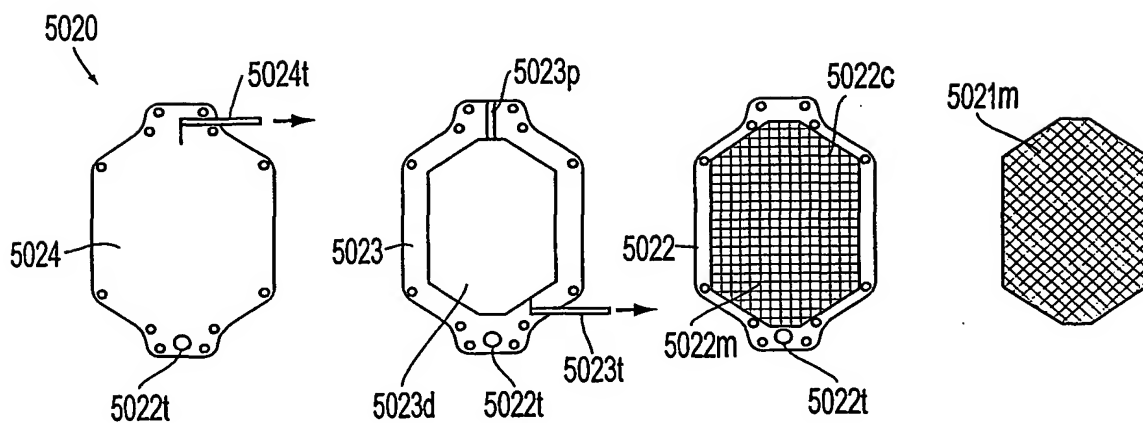


FIG. 5

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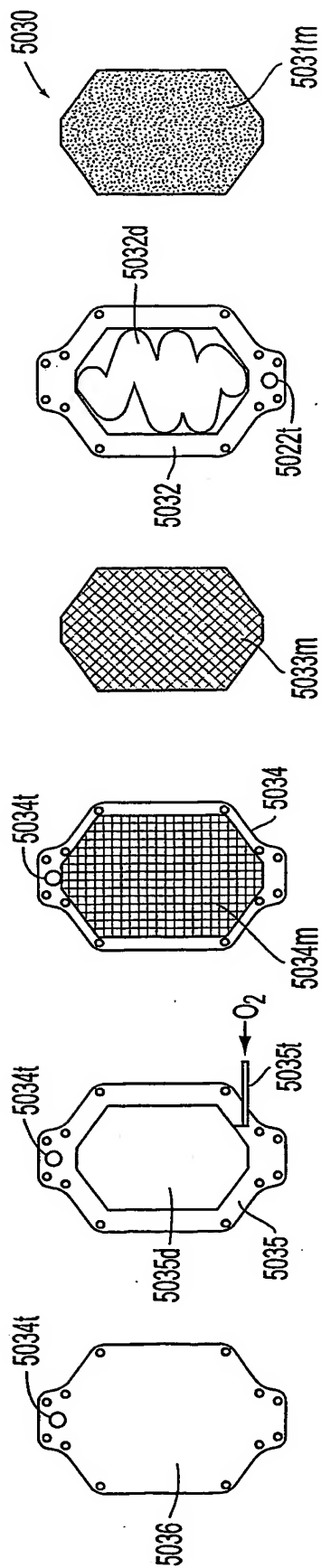


FIG. 6

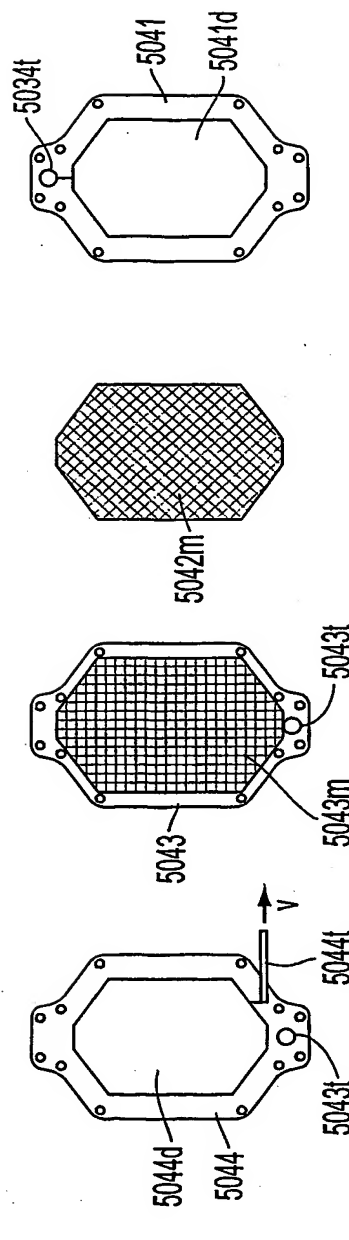


FIG. 7

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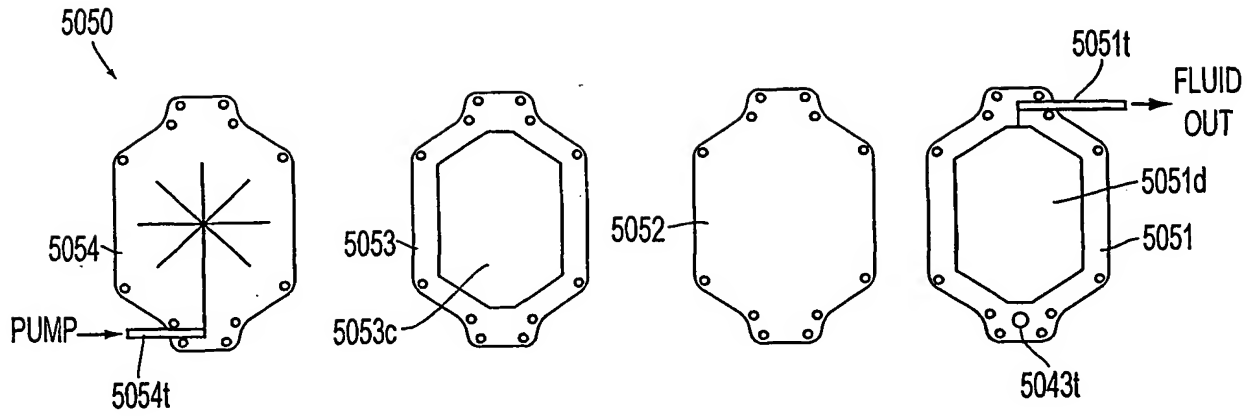


FIG. 8

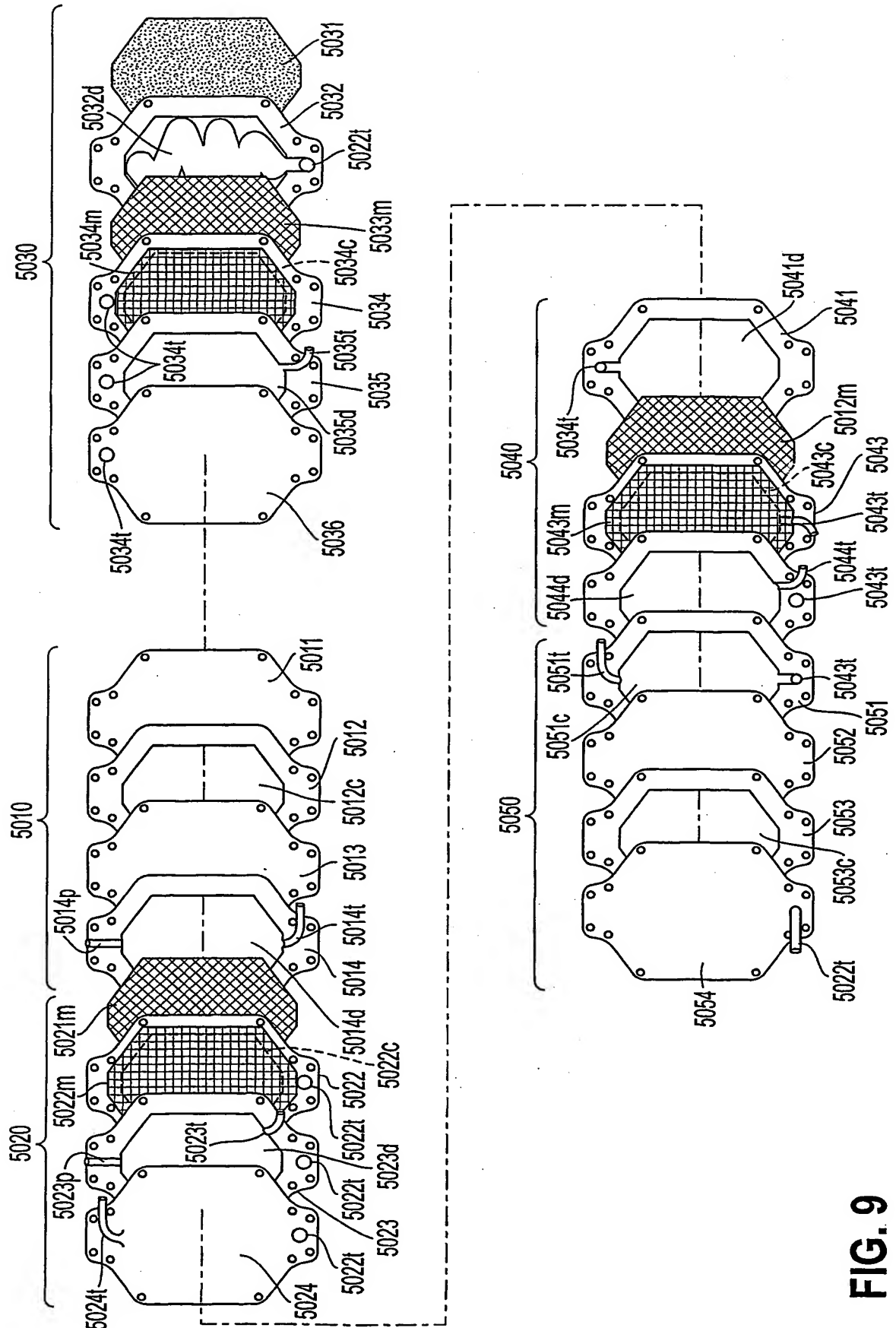
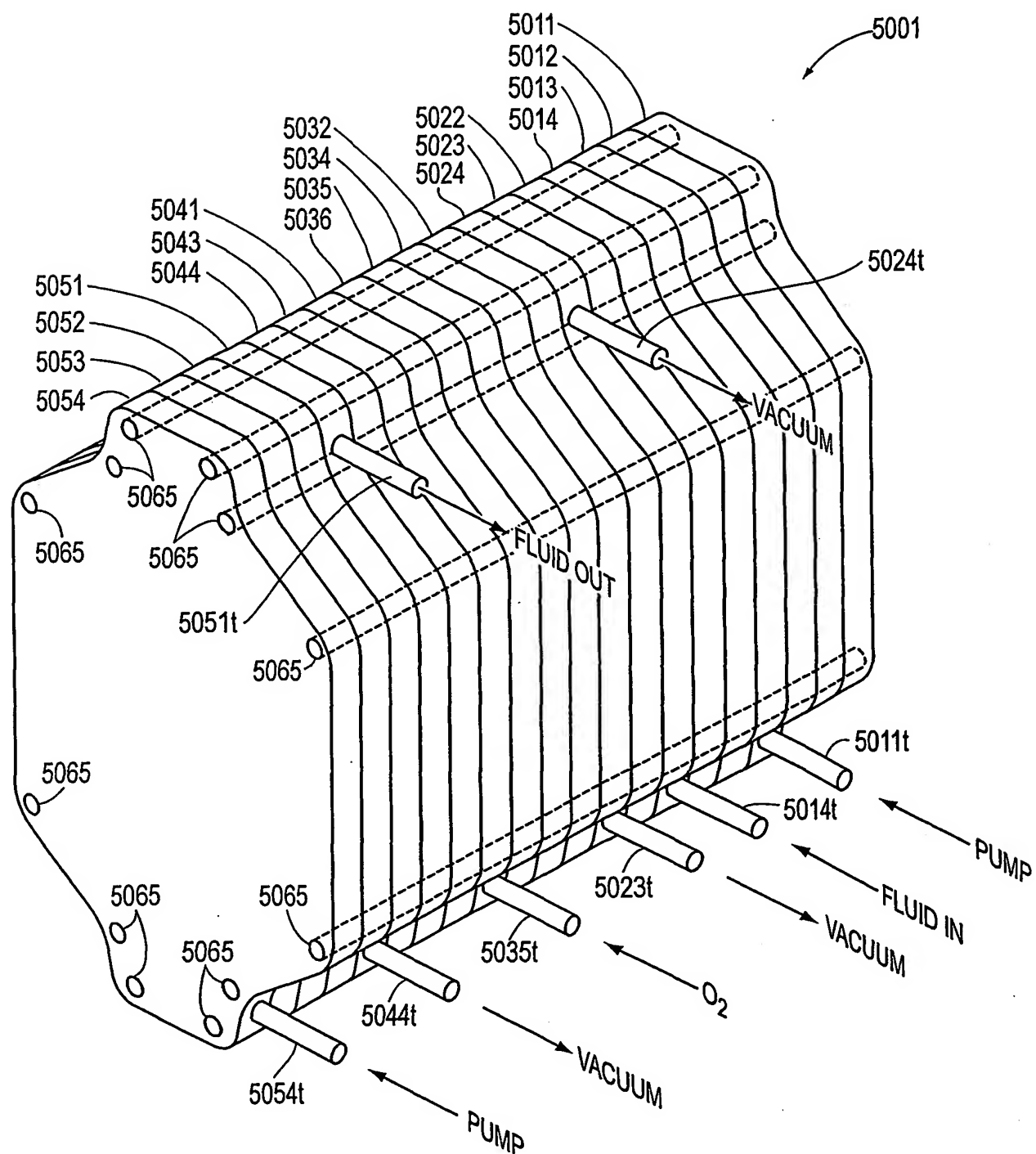


FIG. 9

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**FIG. 10**

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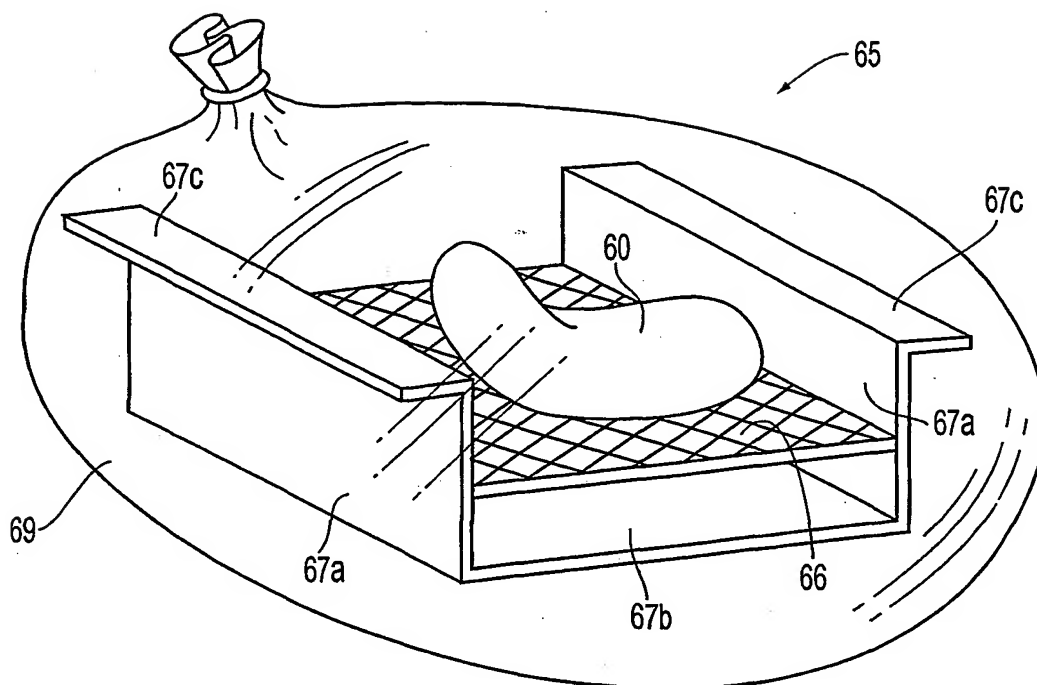


FIG. 11A

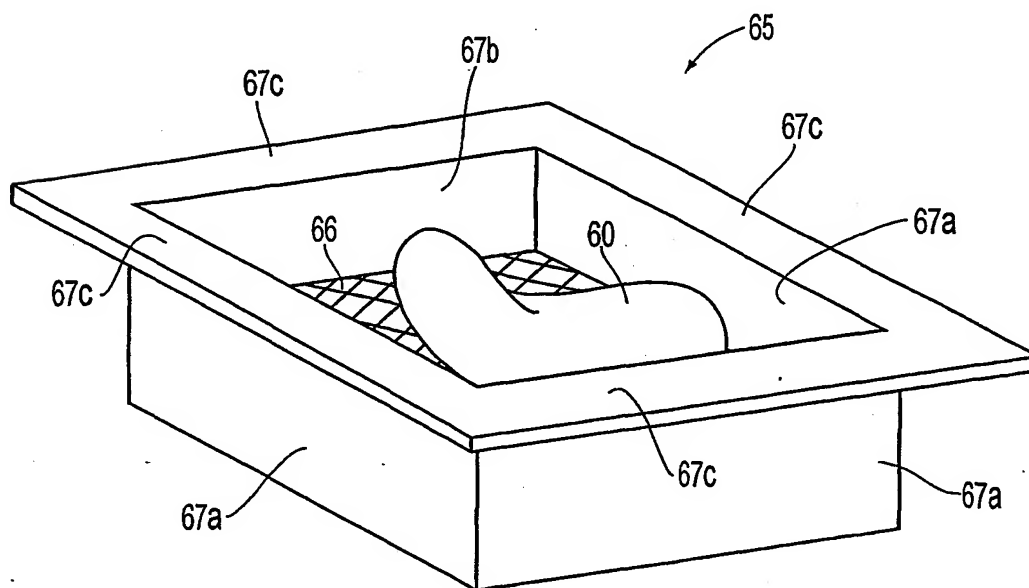


FIG. 11B

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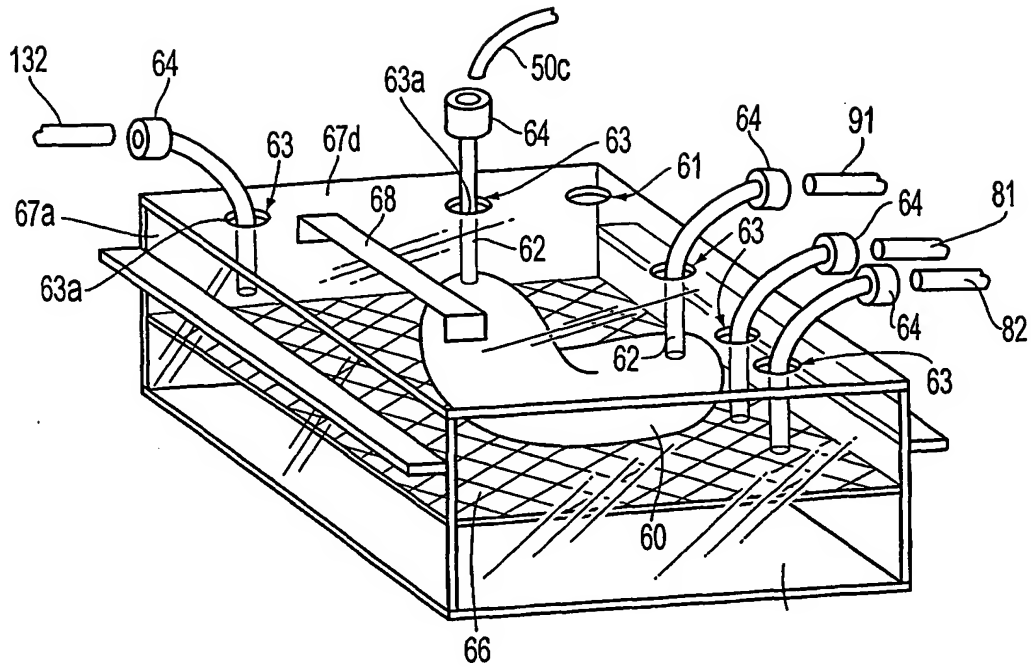


FIG. 11D

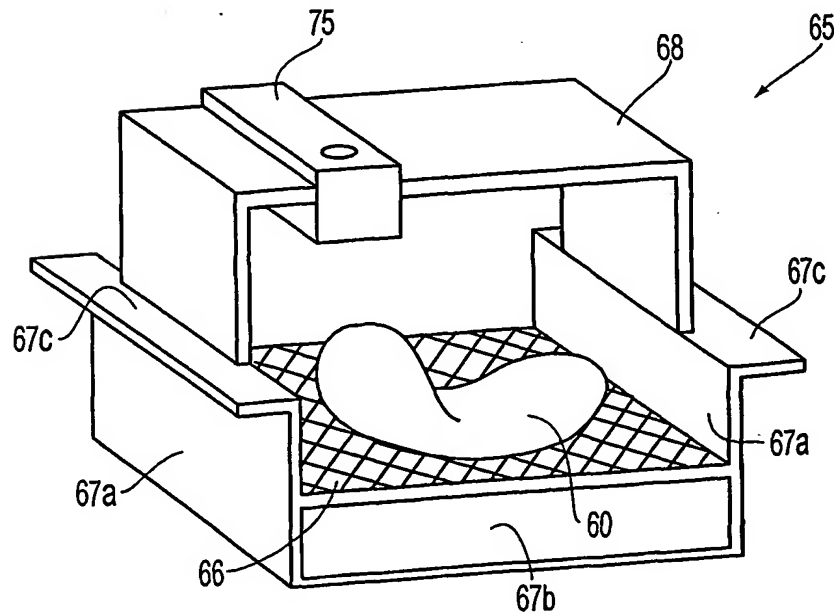


FIG. 11C

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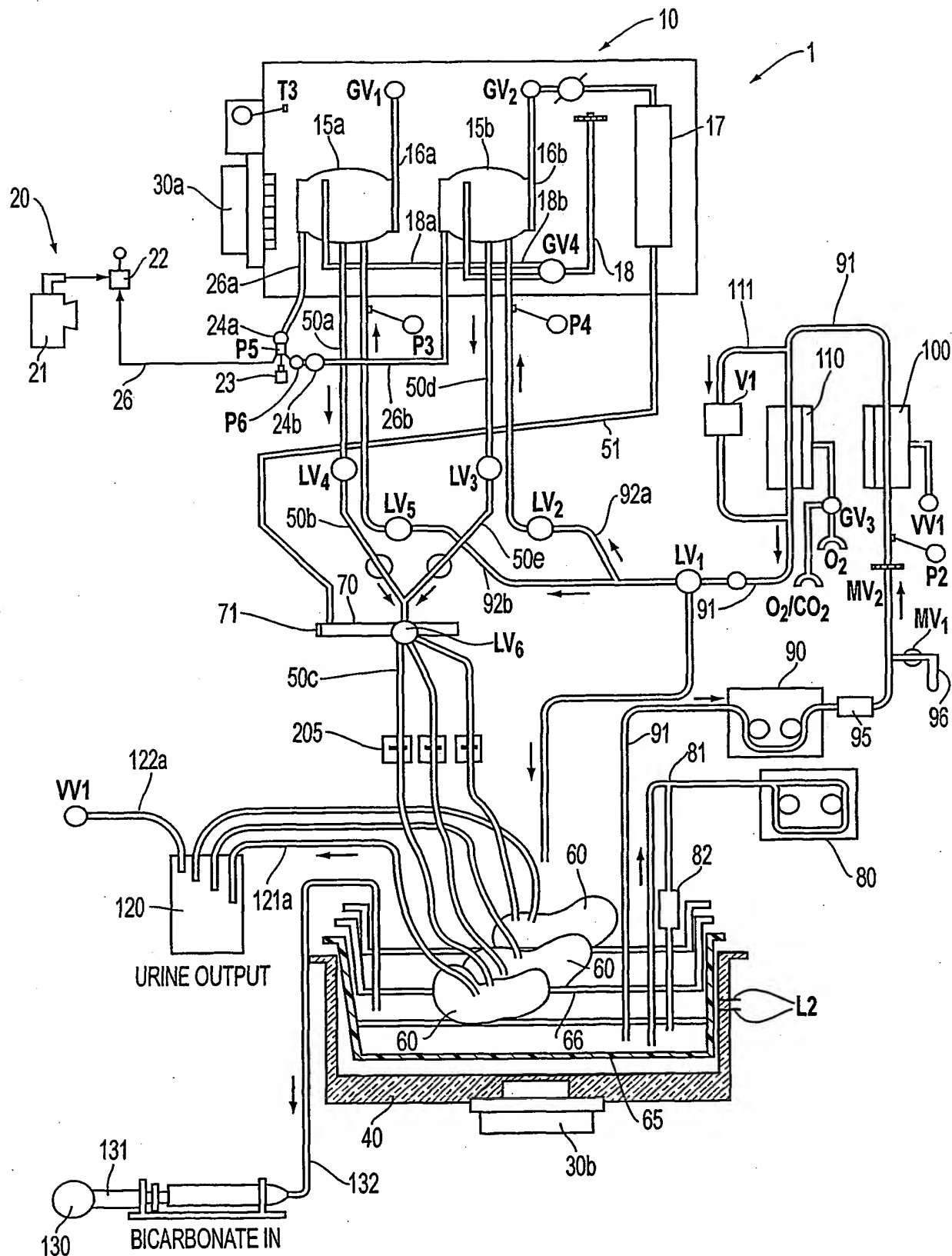


FIG. 12

SUBSTITUTE SHEET (RULE 26)

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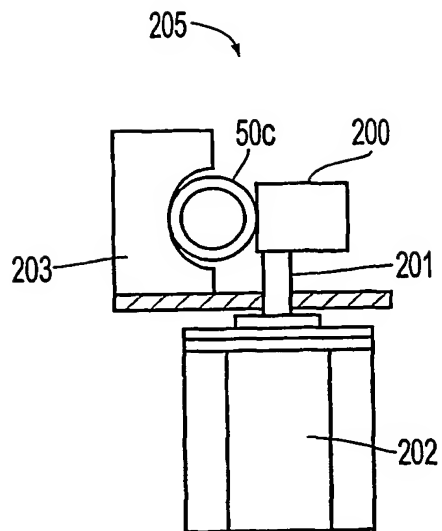


FIG. 13A

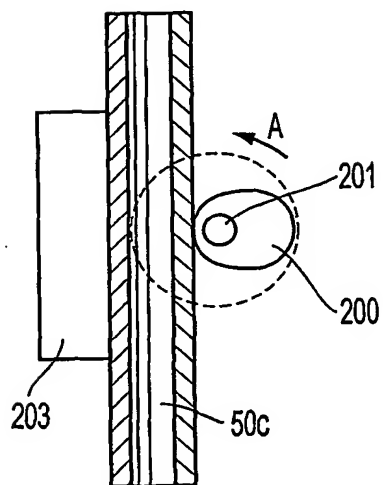


FIG. 13B

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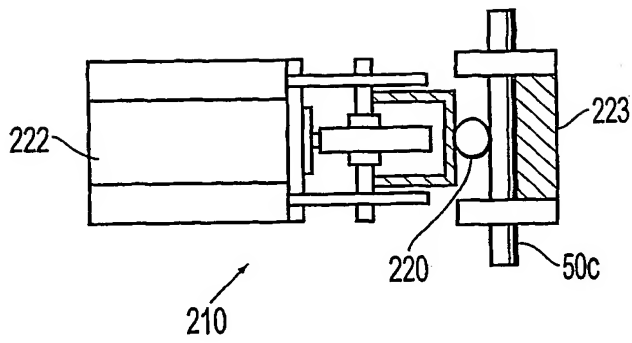


FIG. 14A

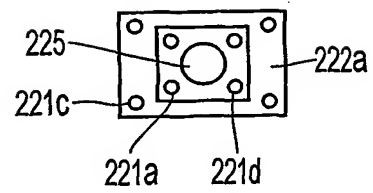


FIG. 14B

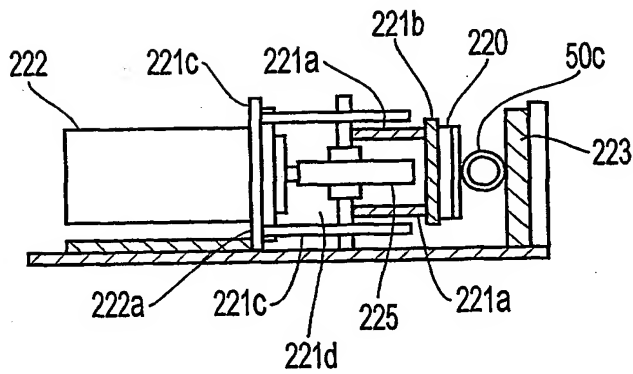


FIG. 14C

FIG. 14D

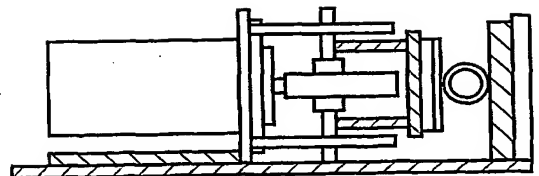


FIG. 14E

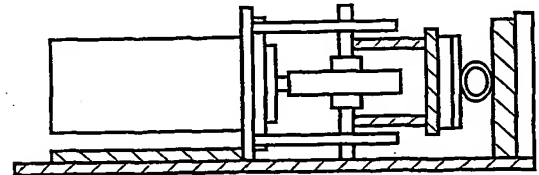
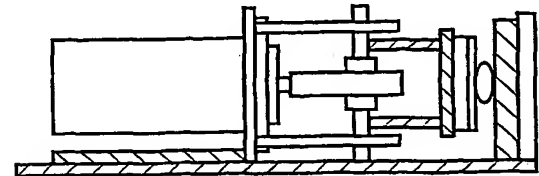
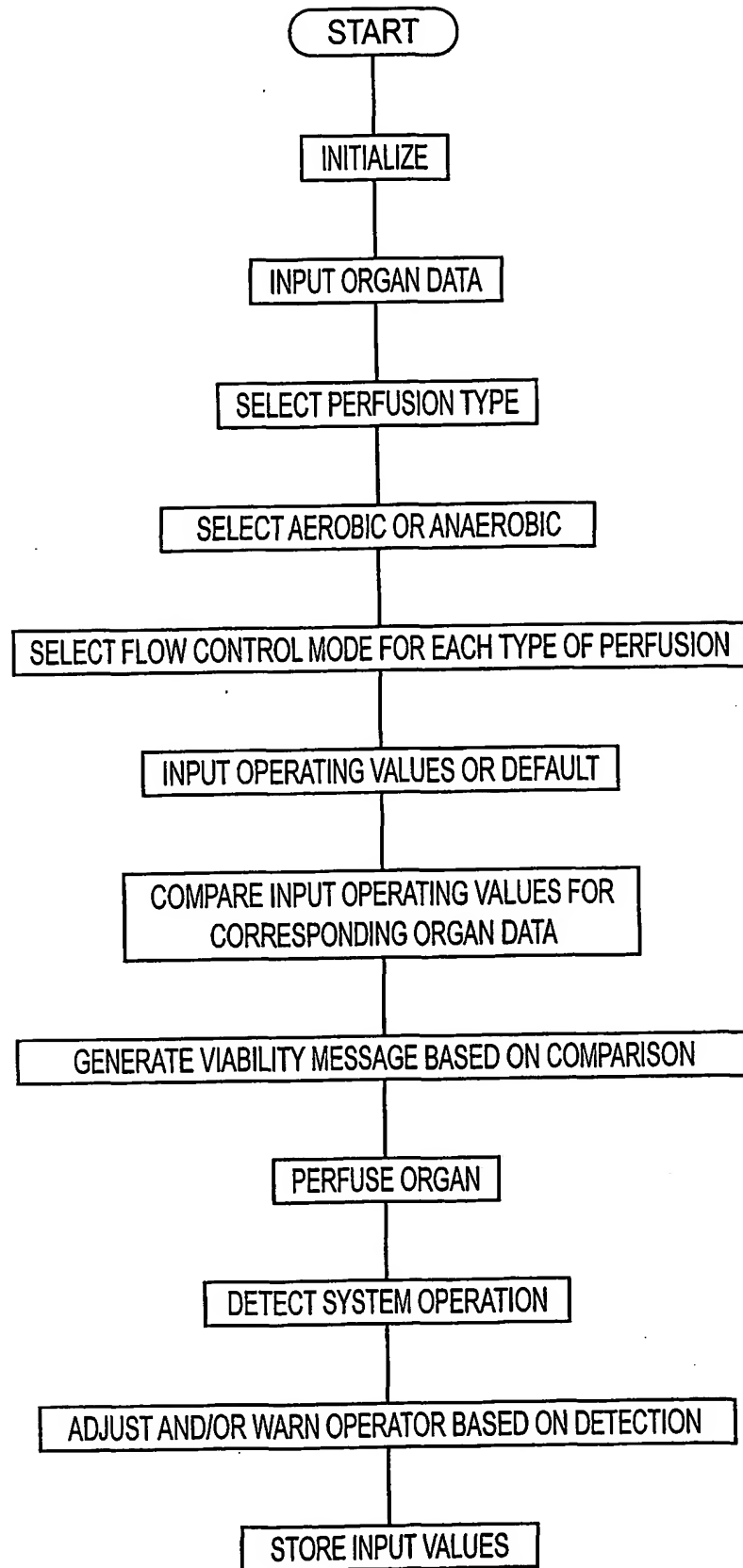


FIG. 14F



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**FIG. 15**

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HYPOTHERMIC MOR ORGAN RECOVERY

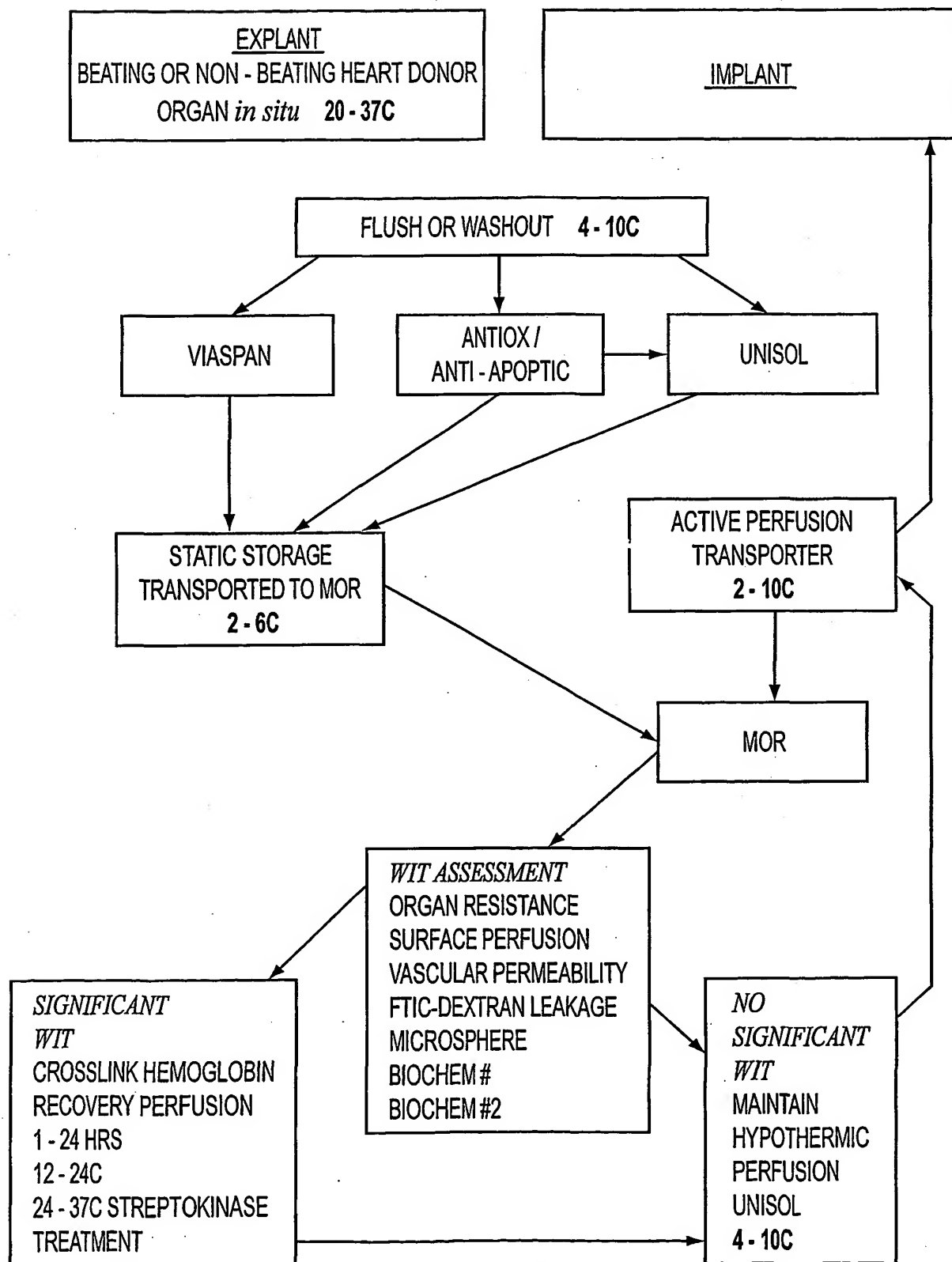


FIG. 16

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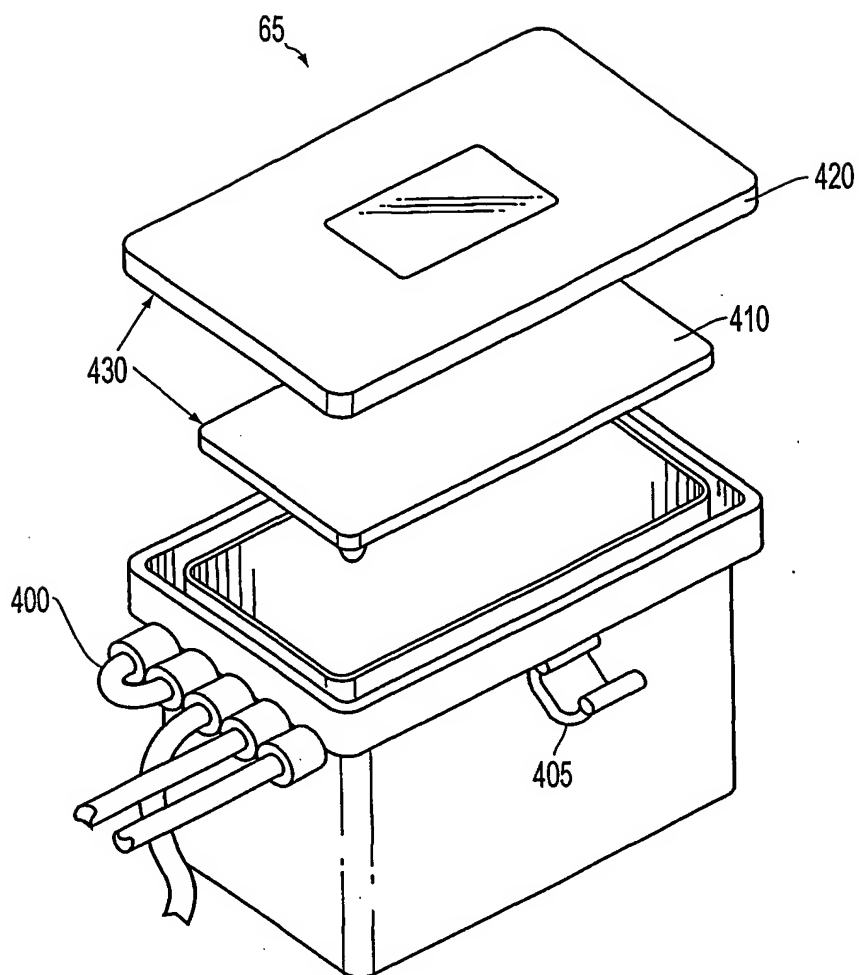


FIG. 17

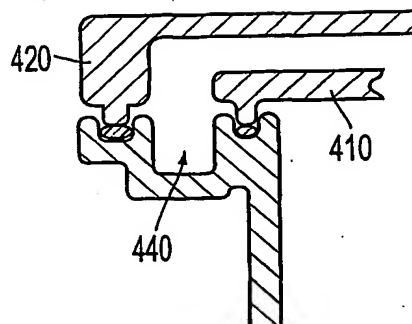


FIG. 17A

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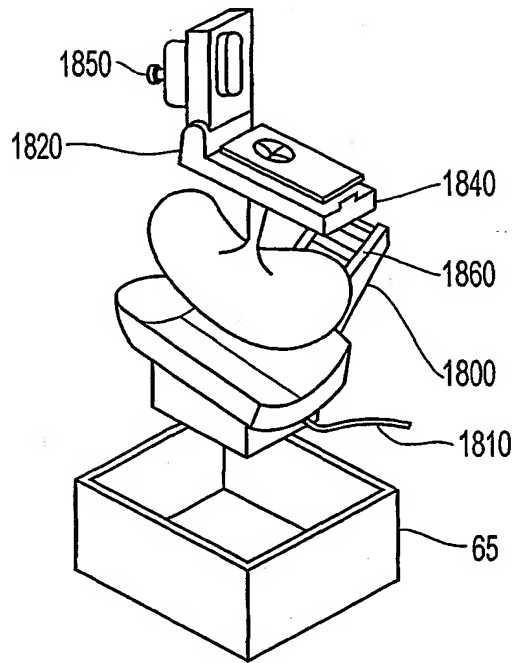


FIG. 18

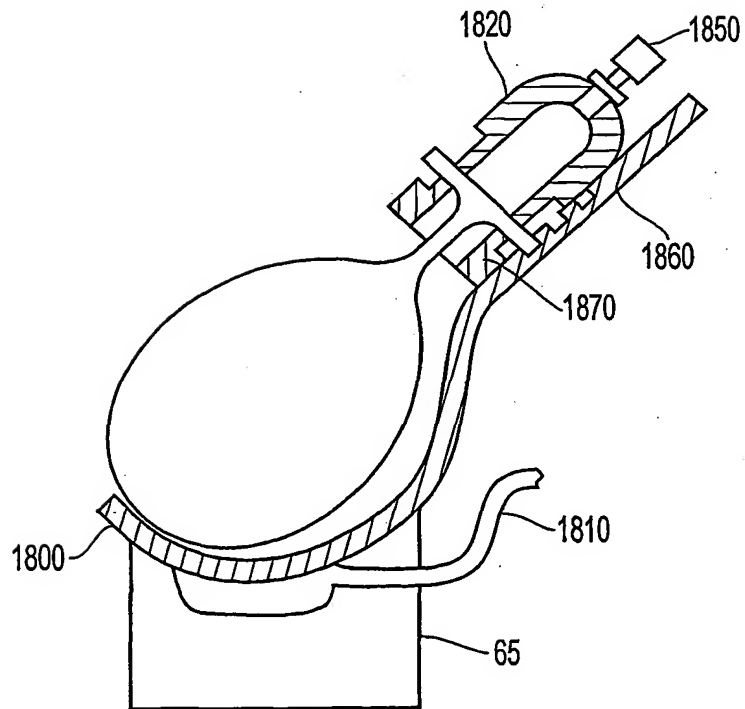


FIG. 18A

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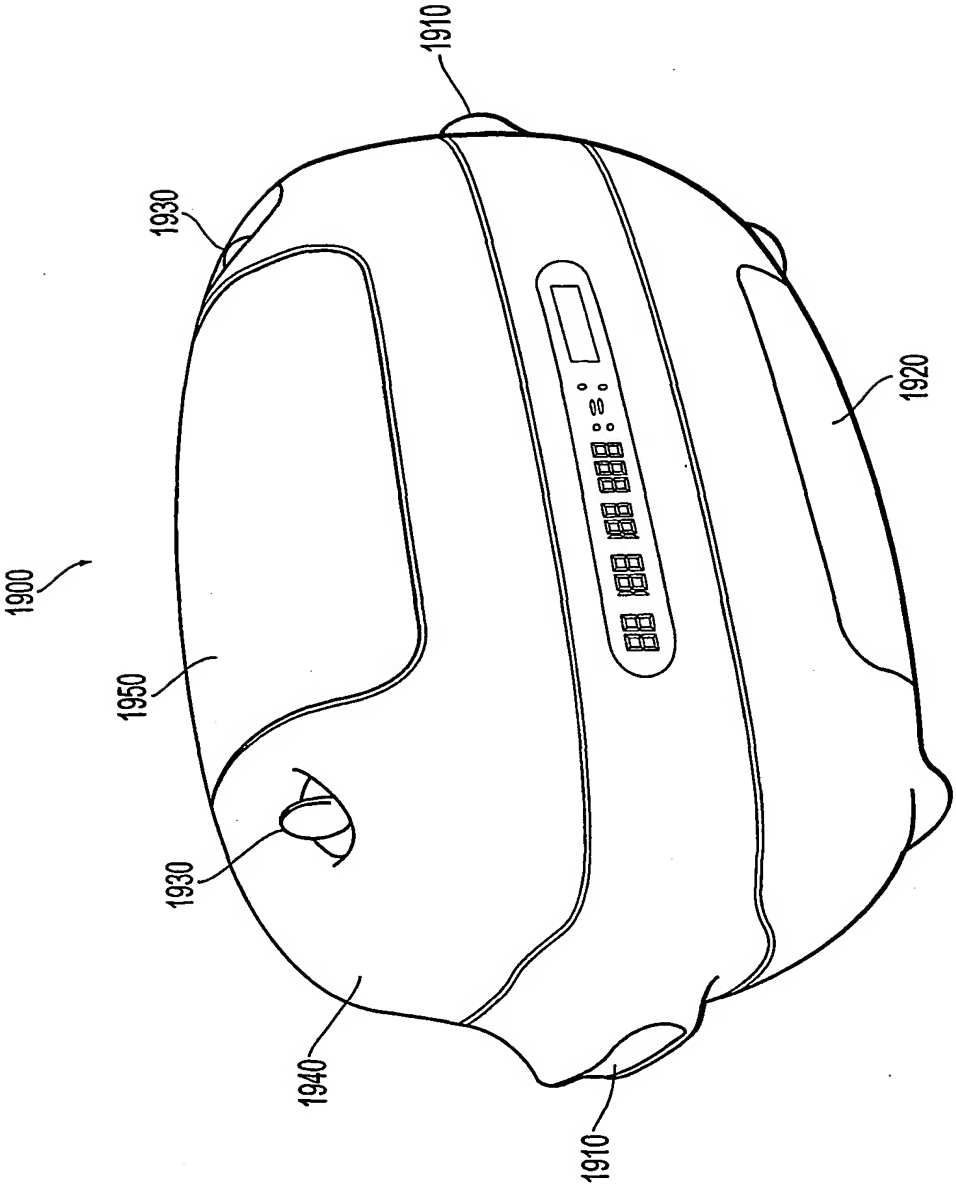


FIG. 19

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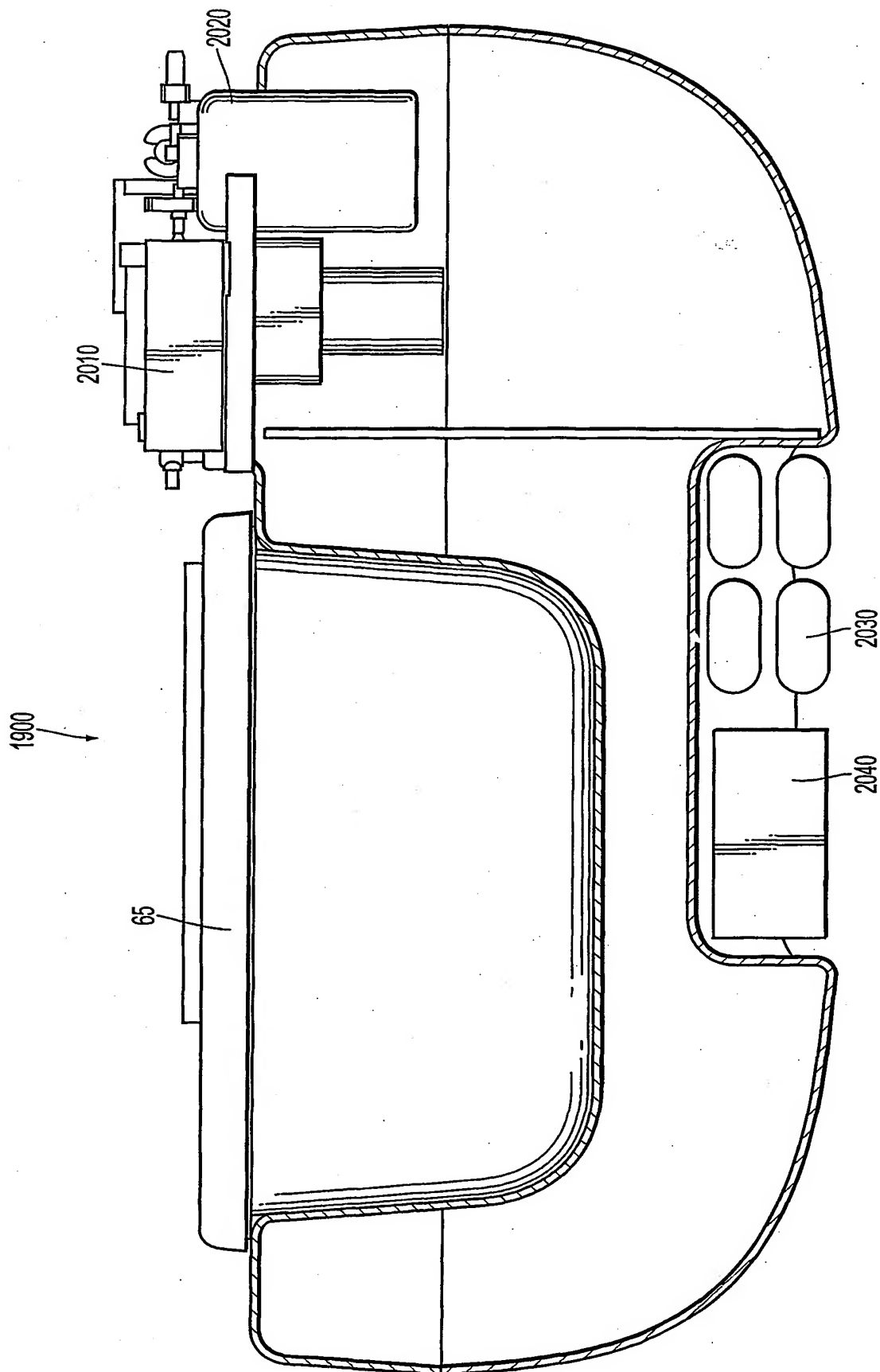


FIG. 20

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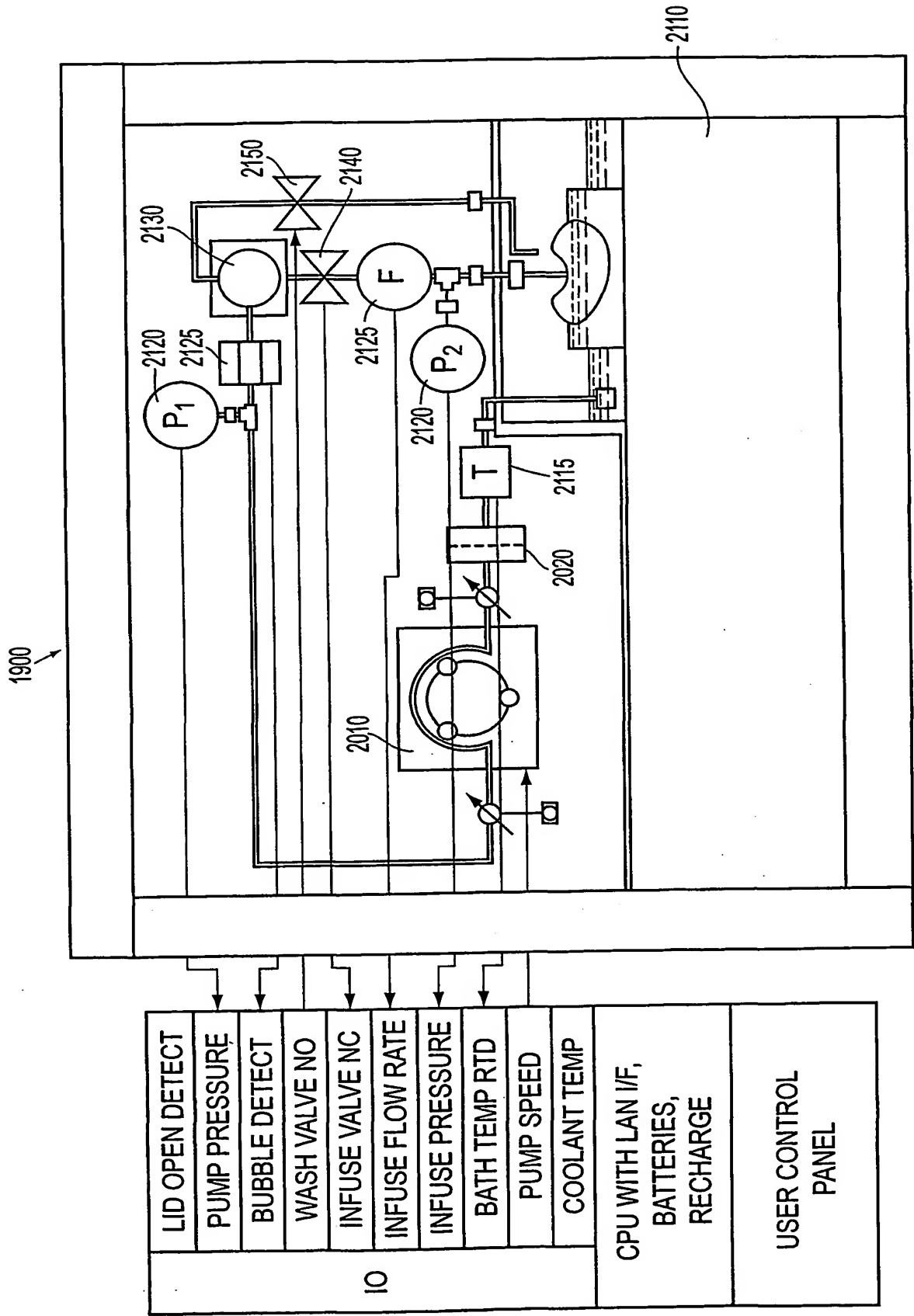


FIG. 21

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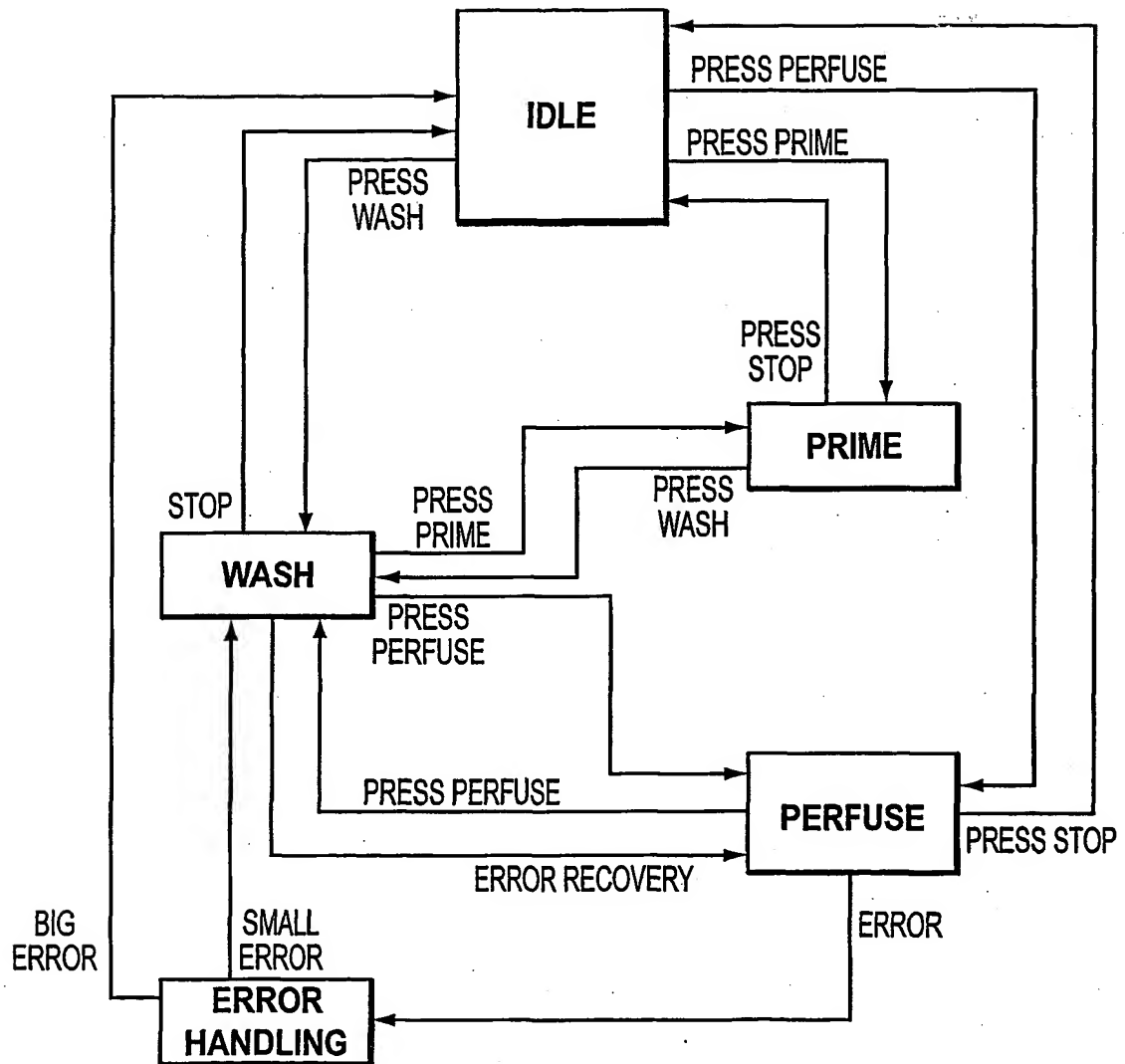


FIG. 22

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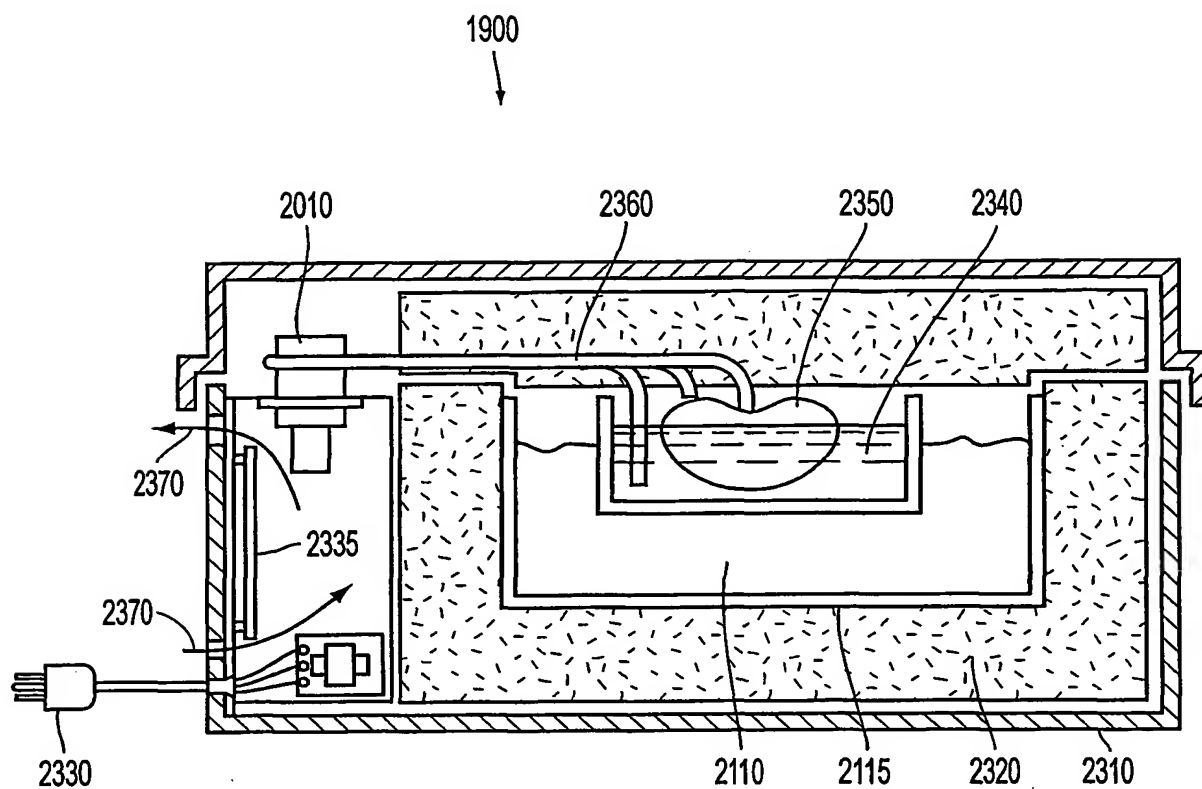


FIG. 23

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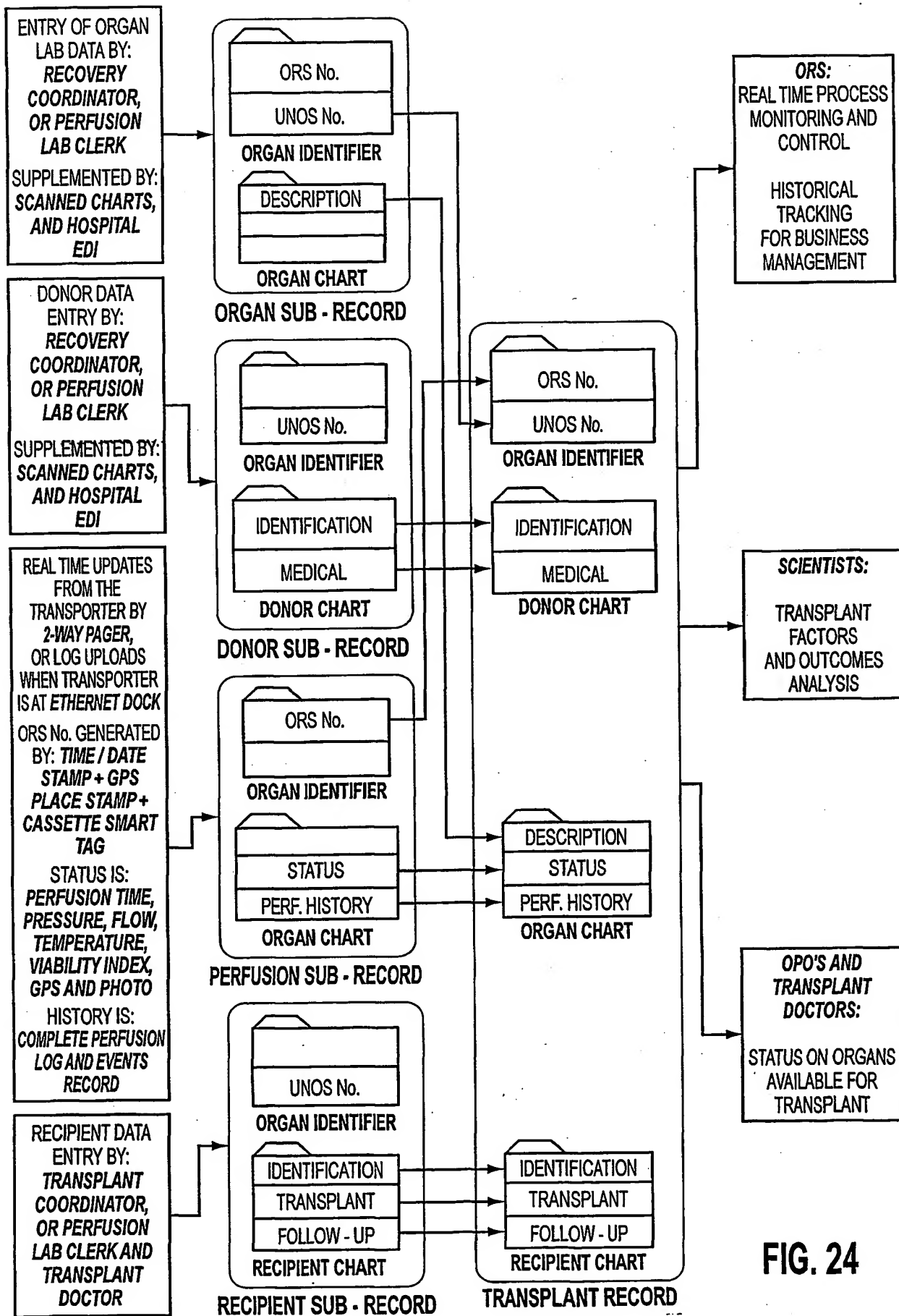


FIG. 24

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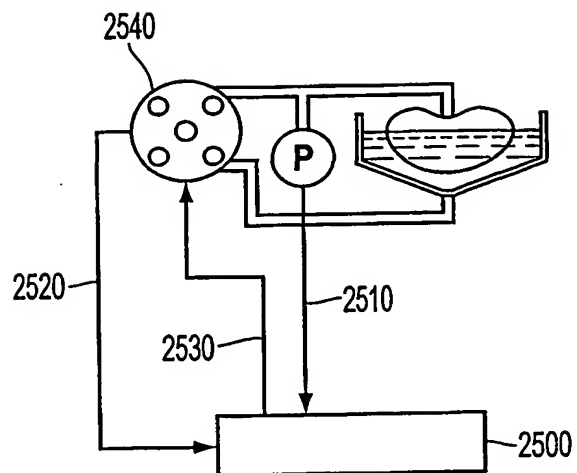


FIG. 25

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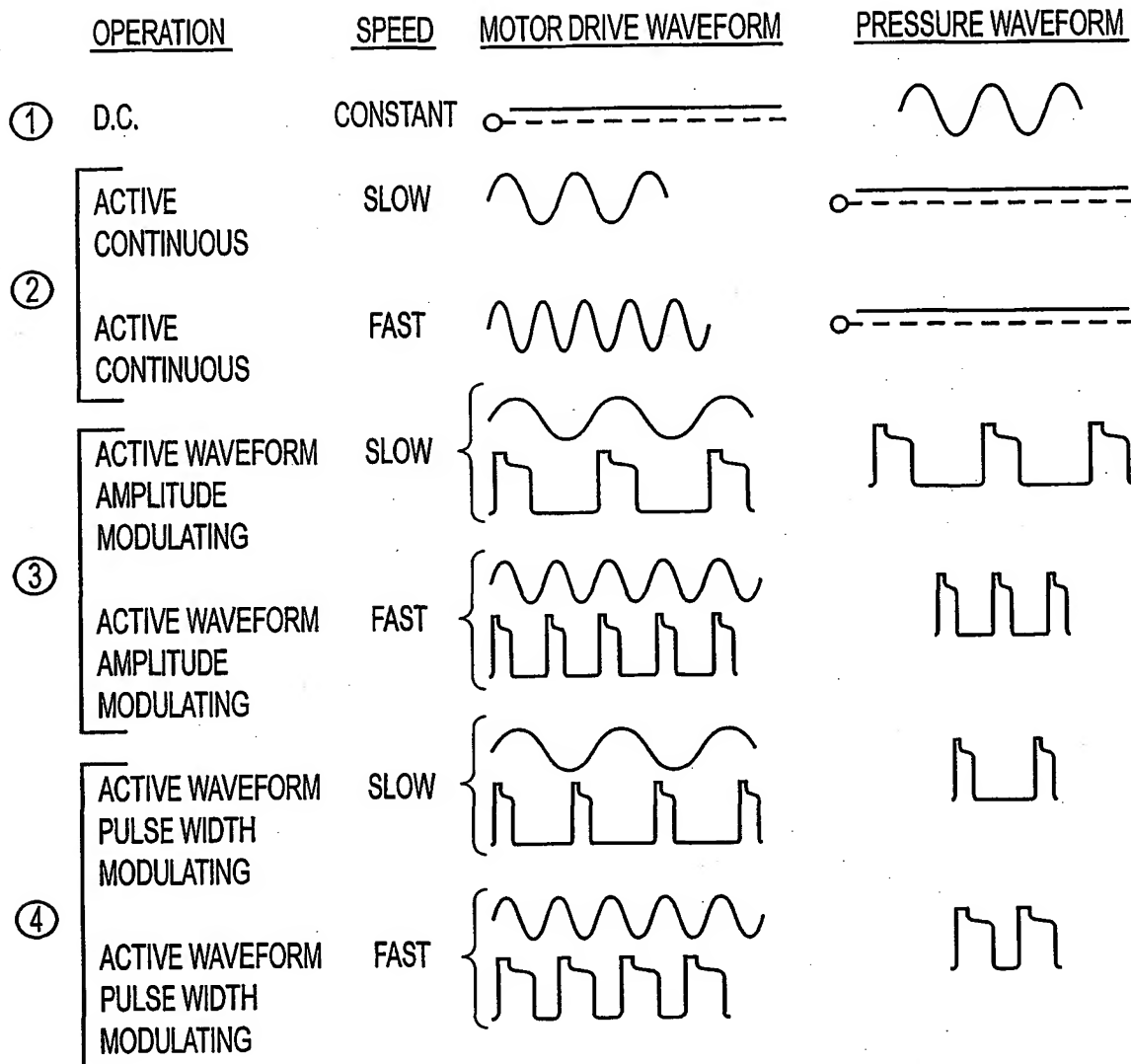


FIG. 25A

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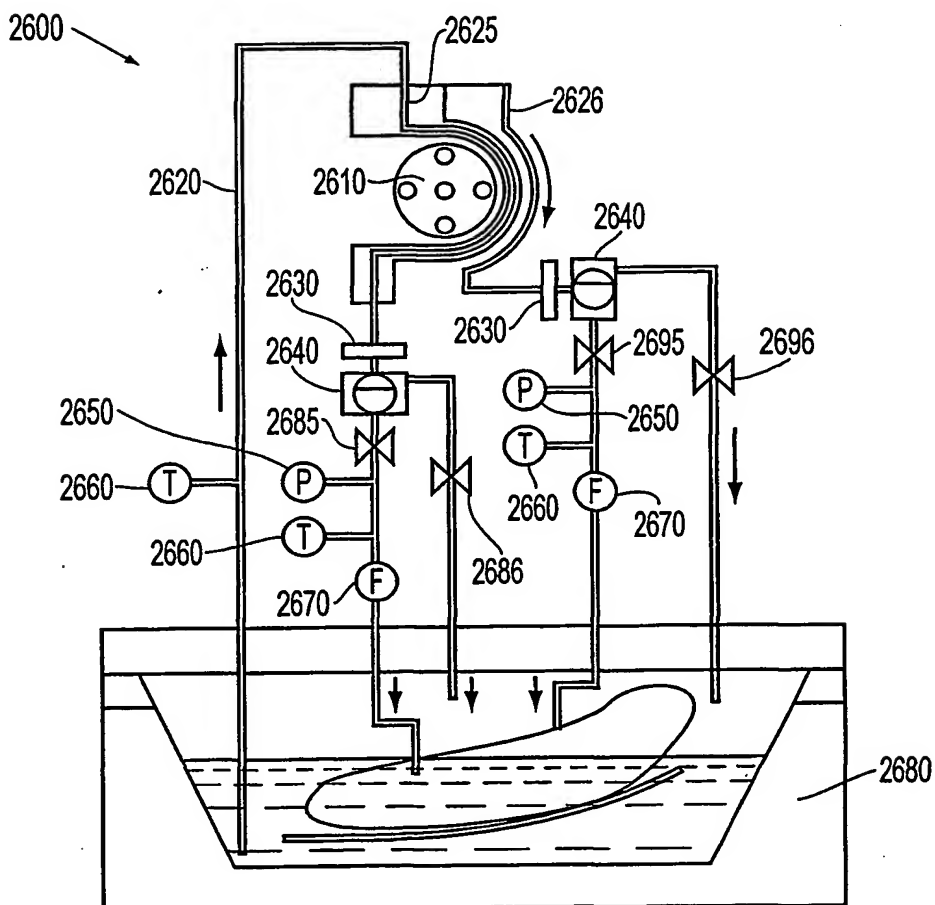


FIG. 26

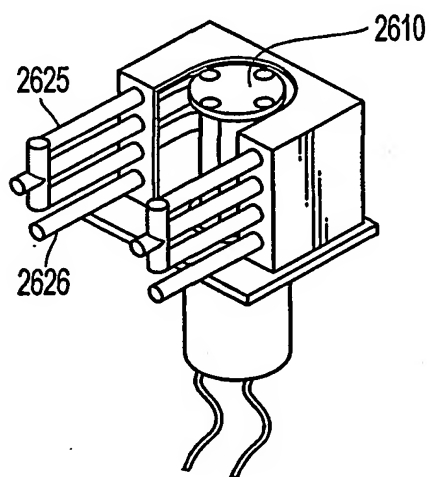


FIG. 27

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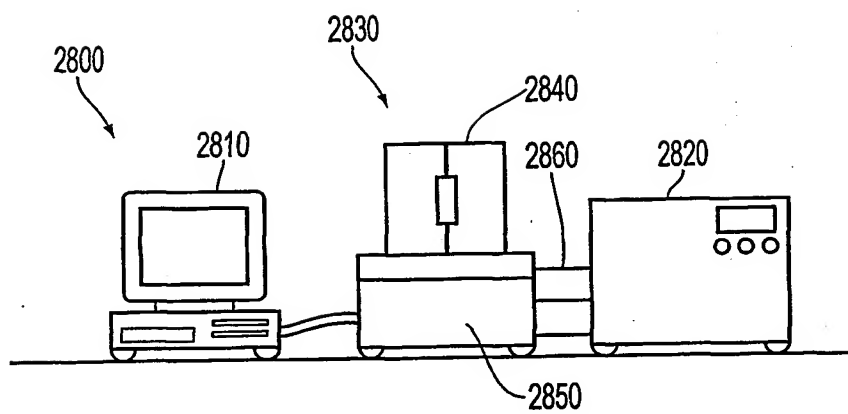


FIG. 28

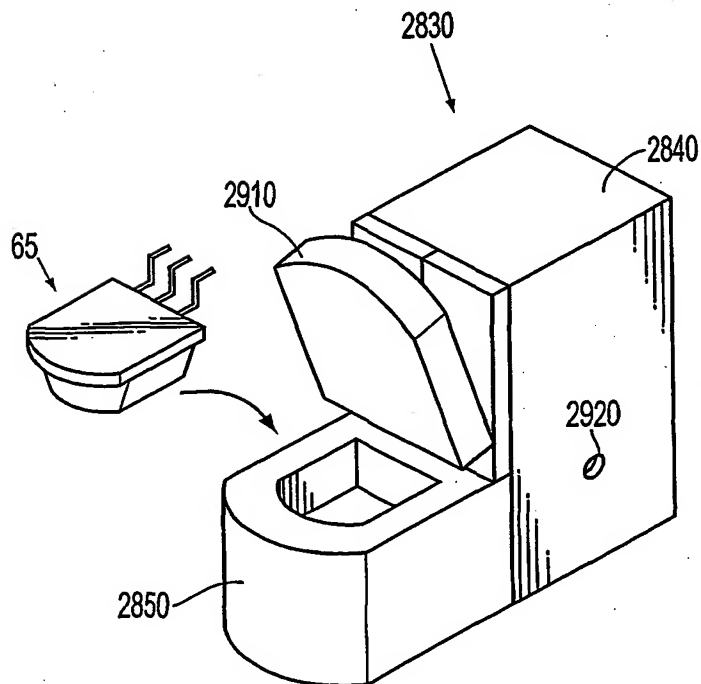


FIG. 29

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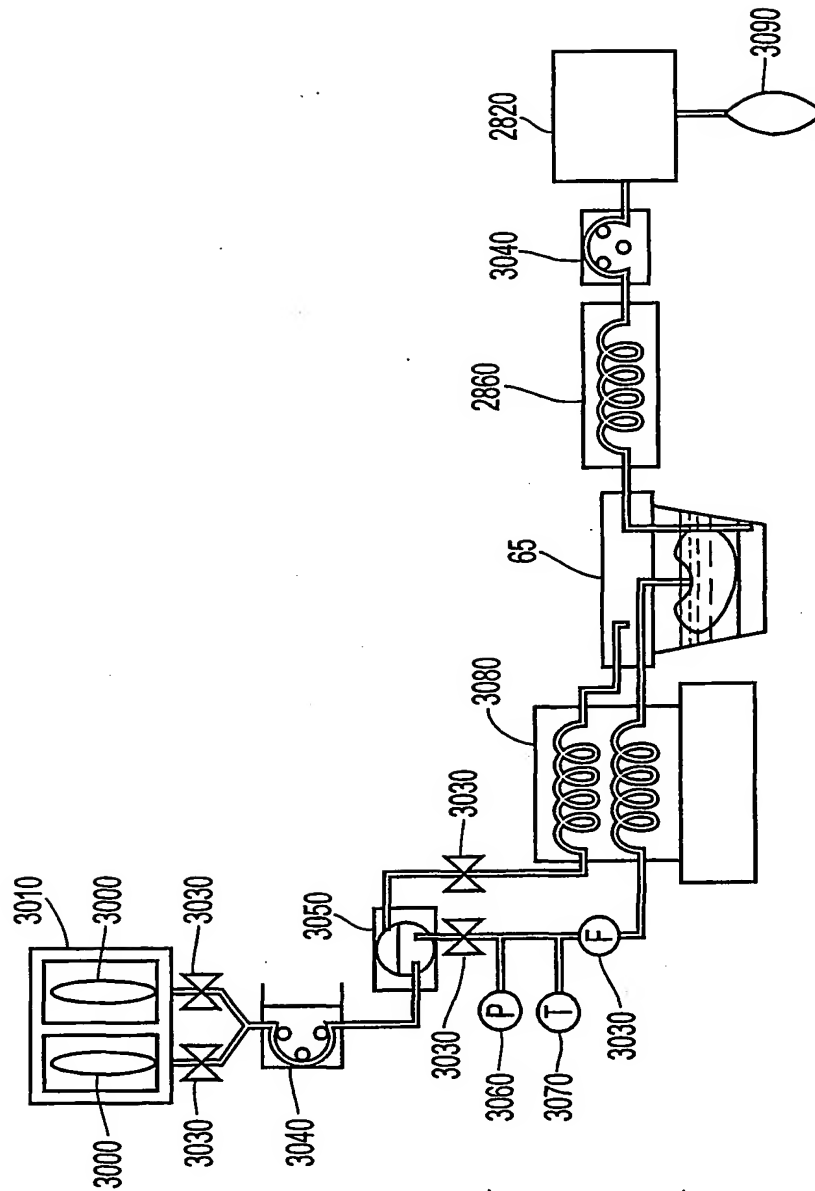
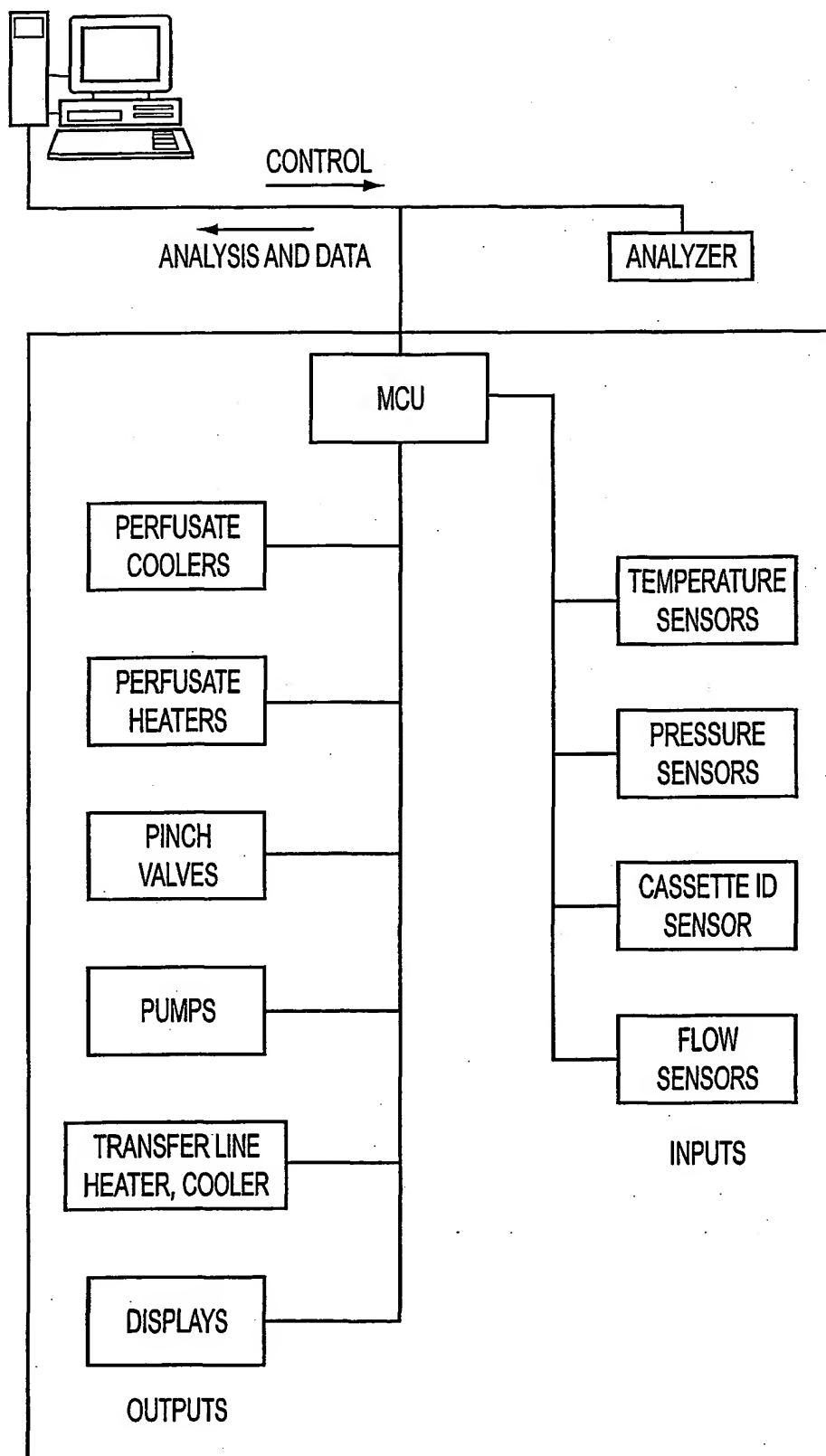


FIG. 30

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**FIG. 31**

SUBSTITUTE SHEET (RULE 26)

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
4 April 2002 (04.04.2002)

PCT

(10) International Publication Number
WO 02/026034 A3

(51) International Patent Classification⁷: **A01N 1/02**

SCHEIN, Douglas; 2420 N. Seminary #1, Chicago, IL 60614 (US).

(21) International Application Number: **PCT/US01/26591**

(74) Agents: **OLIFF, James, A. et al.**; Oliff & Berridge, PLC, P.O. Box 19928, Alexandria, VA 22320 (US).

(22) International Filing Date: 27 August 2001 (27.08.2001)

(25) Filing Language: English

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(26) Publication Language: English

(30) Priority Data:
09/645,525 25 August 2000 (25.08.2000) US

(71) Applicant: **ORGAN RECOVERY SYSTEMS INC.**
[US/US]; 2570 E. Devon Avenue, Des Plaines, IL 60018 (US).

(84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

(72) Inventors: **OWEN, Donald, R.**; Biosyn, Inc., 5700 Citrus Boulevard, Suite B, Harahan, LA 70123 (US). **KRAVITZ, David, C.**; Life Science Holdings, Inc., 2570 E. Devon Avenue, Des Plaines, IL 60018 (US). **BRASSIL, John**; 1137 Jeffrey Court West, Northbrook, IL 60062 (US). **BROCKBANK, Kelvin, G., M.**; 81 Rutledge Avenue, Charleston, SC 29401 (US). **BURROUGHS, Andrew**; 7404 7th Avenue, Kenosha, WI 53143 (US). **ISAACS, Dickon**; 1426 N. Greenvew #2, Chicago, IL 60622 (US). **STEIBEL, Dennis, J.**; 1295 Thorndale Lane, Lake Zurich, IL 60047 (US). **FRASER, Richard**; 2083 Westridge Boulevard, Bortlett, IL 60103 (US). **HARRIS, Stanley**; Organ Recovery Systems, Inc., 701 E. Bay Street, Suite 433, MSC 1119, Charleston, SC 29403 (US).

Published:

— with international search report

(88) Date of publication of the international search report:
20 March 2003

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: APPARATUS AND METHOD FOR MAINTAINING AND/OR RESTORING VIABILITY OF ORGANS

(57) Abstract: An organ perfusion apparatus and method monitor, sustain and/or restore viability of organs and preserver organs for storage and/or transport. Other apparatus include an organ transporter, an organ cassette and an organ diagnostic device. The method includes perfusing the organ at hypothermic and/or normothermic temperatures, preferably after hypothermic organ flushing for organ transport and/or storage. The method can be practiced with prior or subsequent static or perfusion hypothermic exposure of the organ. Organ viability is restored by restoring high energy nucleotide (e.g., ATP) levels by perfusing the organ with a medical fluid, such as an oxygenated cross-linked hemoglobin-based bicarbonate medical fluid, at normothermic temperatures. In perfusion, organ perfusion pressure is preferably controlled in response to a sensor disposed in an end of tubing placed in the organ, by a pneumatically pressurized medical fluid reservoir, providing perfusion pressure fine tuning, overpressurization preventing and emergency flow cut-off. In the hypothermic mode, the organ is perfused with a medical fluid, preferably a simple crystalloid solution containing antioxidants, intermittently or in slow continuous flow. The medical fluid may be fed into the organ from an intermediary tank having a low pressure head to avoid organ overpressurization. Preventing overpressurization prevents or reduces damage to vascular endothelial lining and to organ tissue in general. Viability of the organ may be automatically monitored, preferably by monitoring characteristics of the medical fluid perfusate. The perfusion process can be automatically controlled using a control program.

INTERNATIONAL SEARCH REPORT

International Application No

PCT ; 01/26591

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 A01N1/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 A01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

WPI Data, EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 00 18226 A (LIFE SCIENCE HOLDINGS INC) 6 April 2000 (2000-04-06) the whole document	1-79, 239-241, 262-265
X	WO 96 29865 A (ORGAN INC; LIFE RESUSCITATION TECH (US); AMERICAN NAT RED CROSS (U) 3 October 1996 (1996-10-03) page 7, line 6-20 page 8, line 15-35 page 9, line 36 -page 10, line 14 page 11, line 8-37 page 18, line 35 -page 20, line 22 --- -/--	1-10, 15-47, 52-79, 239-241, 262-265

☒ Further documents are listed in the continuation of box C.☒ Patent family members are listed in annex.

* Special categories of cited documents :

- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier document but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed

- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- "&" document member of the same patent family

Date of the actual completion of the international search

17 June 2002

Date of mailing of the international search report

03.09.02

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Klaver, J

INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 01/26591

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	<p>WO 96 30111 A (ORGAN INC; LIFE RESUSCITATION TECH (US)) 3 October 1996 (1996-10-03) cited in the application</p> <p>page 6, line 23 -page 7, line 1 page 8, line 18 -page 9, line 13 page 12, line 18-34 page 15, line 30 -page 16, line 14 page 27, line 34 -page 28, line 37 -----</p>	<p>1-10, 15-47, 52-79, 239-241, 262-265</p>

Form PCT/ISA/210 (continuation of second sheet) (July 1992)

page 2 of 2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 01/26591

Box I Observations where certain claims were found unsearchable (Continuation of Item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of Item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-79, 239-241, 262-265

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.
- ☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. Claims: 1-79, 239-241, 262-265

a). Apparatus for holding an organ comprising a portable housing and an organ supporting surface, wherein the portable housing is configured to be received by at least one of a perfusion device, an organ transporter and an organ diagnostic device and includes openings to allow tubing to pass therethrough and be connected to the organ and wherein a bottom portion of the housing is liquid tight.
(Claims 1 - 36, 44 - 79 and 262 - 265)

b). Saleable kit comprising
- a portable housing
- an organ supporting surface, wherein the portable housing is as defined under a) above
- tubing connectable to the organ and
- at least one connection device to allow connection of the tubing to one of the devices.
(Claims 37 - 43)

c). Apparatus for holding an organ comprising a portable housing, a pump and an organ supporting surface wherein the pump is connected to at least two different areas of an organ with at least two different tubes.
(Claims 239 - 241)

2. Claims: 80 - 105, 167 - 169, 192, 193

a). Method of controlling perfusion of an organ with a medical fluid comprising one or more of
- inputting organ data
- selecting a perfusion mode
- selecting a type of flow control for each selected mode
- controlling the fluid flow based on the selected perfusion mode and flow control
- detecting operating conditions experienced by the fluid and organ during perfusion
- comparing detected conditions with prestored ones and generating a signal indicative of organ viability based on the comparison and
- generating a message relating to organ viability based on the generated signal and/or making automatic adjustments to regulate viability.
(Claims 80 - 92, 192)

b). Recording medium that stores a control program including instructions for the various steps as defined in the method under a).
(Claims 93 - 105)

c) Method of perfusing an organ comprising perfusing an organ with a medical fluid, collecting the fluid that has passed the organ, passing the collected fluid through a sensor and determine the organ viability
(Claims 167 - 169)

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d) Control system for controlling perfusion comprising at least one of the devices necessary for each of the steps mentioned under a) above.
(Claim 193)

3. Claims: 106 - 156

Method of maintaining and/or restoring viability of an organ subjected to a period of ischemia or hypoxia comprising at least one of perfusing and flushing said organ with a first medical fluid at a first hypothermic temperature to reduce or stop catabolic changes.
Flushing may be performed prior or subsequent to the perfusion step.
Method may further comprise a second perfusion step with a second (preferably oxygenated) fluid at a different temperature.

4. Claims: 157 - 161

Method of maintaining and/or restoring viability of an organ subjected to a period of ischemia or hypoxia comprising perfusing said organ with a first medical fluid at a first temperature to reduce or stop catabolic changes and perfusing the organ with a second (preferably oxygenated) fluid at a second temperature to store and/or transport the organ.

5. Claims: 162-166

Method of perfusing an organ comprising perfusing the organ utilizing a medical fluid reservoir in communication with a pressure source and a fluid pathway, wherein reservoir and pathway are configured to perfuse the organ at a pressure that is controlled either by a pressure source that is a cuff disposed around the container or by a variable valve or a pressure head disposed on the pathway.

6. Claims: 170 - 178

Method of transporting or storing an organ comprising
a) perfusing the organ at a mild hypothermic temperature to repair damage from warm ischemia, preferably with an oxygenated fluid;
b) perfusing the organ at a hypothermic temperature, such as one that is less than the temperature in step a), preferably with a non-oxygenated fluid;
c) transporting and/or storing the organ at a mild hypothermic temperature such as a temperature that is greater than in step b); and
d) perfusing said organ at a mild hypothermic temperature to

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repair damage from hypothermic transport or storage of step c).

7. Claim : 179

Apparatus for perfusing an organ comprising:
a medical fluid reservoir;
a fluid pathway connected to the reservoir and connectable to the organ;
a first heat exchanger in communication with the fluid reservoir;
and a controller for controlling the heat exchanger to allow perfusion at various hypothermic temperatures.

8. Claims: 180 - 191

A perfusion solution kit comprising a saleable package containing a first container holding a first perfusion solution for hypothermic perfusion at a first T and a second container holding a second, different solution for hypothermic perfusion at a second T, which is lower than the first T.

9. Claims: 194 - 228, 284 - 294

Portable transporter for holding a portable housing comprising:
a base portion to facilitate an upright position of the transporter;
a top portion;
a pump;
a power supply;
a compartment for holding a portable housing configured to hold at least one organ, optionally comprising further constructional or controlling elements such as tube sets, latches, wheels or a control panel or an additional compartment for holding a coolant .

10. Claims: 229 - 234

Method of controlling operation of a transporter comprising:
using a set of controls provided on the transporter to select an operation; and
displaying the operation selected, which operation is at least one of priming, washing, error handling, perfusing and idle.

11. Claims: 235 - 238

Apparatus for holding an organ comprising:

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

a portable housing;
a pump;
a pulse controller; and
an organ supporting surface wherein pump and pulse controller receive at least one of flow data, tachometer data and pressure data from a pressure sensor and converts the data into an output to drive the pump.

12. Claims: 242 - 248, 261

- a). Organ assessment system comprising an organ support and at least one organ parameter sensor; an organ perfusion apparatus, wherein the system is adapted to assess the organ parameters while maintaining the status of the organ during the assessment (claim 242).
- b). Organ assessment system comprising a computer, an analyzer, an organ evaluation instrument in (wired or wireless) communication with computer and analyzer, a perfusate chamber and an organ chamber configured to receive an organ (claims 244 - 247).
- c). Method of assessing an organ comprising holding an organ, sensing an organ parameter and diagnosing the organ during a time the organ is held (claim 243).
- d). Method of analyzing the viability of an organ comprising detecting organ parameters, compiling the organ parameters and producing an index of viability of the organ based on the compiled parameters (claim 248).
- e). Method of determining the viability of an organ comprising flushing the organ, string the organ in a transporter at cold T, assessing the viability and transporting viable organs to implant sites (claim 261).

13. Claims: 249 - 260

Method of improving an organ or a tissue comprising removing the organ/tissue from a body, enhancing the organ/tissue, e.g. by radiation or chemotherapy, and implanting the enhanced organ/tissue into a body.

14. Claims: 266 - 275, 283

- a) A method of remotely monitoring an organ comprising remotely monitoring information during transportation and storage, e.g. monitoring location or viability parameters of the organ (claims 266 - 270).
- b). Transporter for carrying an organ comprising an information transmission device such as GPS (claims 271 - 275, 283).

15. Claim : 276

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Organ transportation device comprising a transporter and a portable housing fit securely together to provide high efficiency heat transfer.

16. Claims: 277 - 280

Kit comprising a saleable package containing a set of tubes configured to connect an organ to a perfusion apparatus.

17. Claims: 281, 282

Apparatus for holding an organ comprising a portable housing and a removable organ supporting surface.

18. Claims: 295, 296

Apparatus for holding an organ comprising a sensor to detect the presence of a portable housing for an organ in the apparatus.

19. Claim : 297

Method of analyzing factors involved in organ transplantation or implantation comprising comparing outcomes of organ transplants in recipients and comparing organ history during transport and/or storage.

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International Application No

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